# INFLUENCE OF PARTICLE SHAPE AND VOID RATIO
# ON
# BASE STABILITY

A report submitted in partial fulfilment
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**ABSTRACT**

In this investigations, the effects of particle shape and gradation on the performance of unbound granular pavements were examined. The test was carried out on full scale road structures at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF).

Rounded and angular aggregates with different gradations were tested as a basecourse layer in flexible pavements for which suitable subgrade was provided and the subbases were excluded.

Density, moisture content, and sieve analysis tests were carried out before and after the experiment. Deflections and vertical deformations were measured frequently after specified intervals of loading.

Performance was evaluated by comparing compactive effort, deflections and vertical deformations. The cohesiveness of fines and blending of materials were found to be important factors. Particle shape has relatively greater influence on the performance than the aggregates' gradation.

## ACKNOWLEDGEMENT

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The generous financial support for this research was provided by the National Roads Board, Wellington.

Finally, the author would like to dedicate this report to his family.

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# CHAPTER I

# INTRODUCTION

## 1.1 Introduction

New Zealand has a huge quantity of river deposits, which tend to be rounded aggregates. It is desirable to accommodate the widest possible range of aggregate types, while satisfying other criteria, in the specifications. While framing the specifications, economic and technical factors should be considered. The use of locally available material for road construction is a very common practice to achieve economy in roading projects. For example, the use of rounded aggregates minimises aggregate crushing cost. The specifications are updated periodically, taking in to account the past performances of pavements and the recommendations of various research projects.

The purpose of this research project described in this report is to check the performance of rounded and angular aggregates. In an unbound flexible pavement structure, the performances depends mainly on the subbase and basecourse aggregates, subgrade material, drainage conditions and loading pattern. Using the specific maximum size, specific percentage of each size and shape of aggregates is a proven method of improving performance of unbound flexible pavement. In addition it also improves the performance of other factors, for example drainage. Timpany (1974) , Yeoh (1978) and other researchers have shown that particle shape and void ratio influence the stability of an unbound flexible pavementts's basecourse.

The performances of different types of aggregates, shape and void ratio were evaluated by conducting full scale tests, carried out at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) in Christchurch.

## 1.2 Need for the Research

The National Roads Board, through its Road Research Unit (RRU), has been carrying out research on unbound granular pavements since 1969 (Smith 1974). For example RRU Research Project No. BC/2, titled "Factors which affect the stability of unbound basecourse pavements", was conducted to compare the properties of `sound' and `failing' unbound thin surfacing pavements (Tonkins and Taylor 1972 ).

The influence of shape and gradation on unbound granular basecourses with thin surfacing was examined in RRU Research Project No. BC/19, titled " The influence of particle shape and grading on the performance of unbound basecourse material" (Yeoh 1978). The research was divided into two distinct stages, viz. laboratory tests and full scale road structure tests at The University of Canterbury Pavement Test track. Laboratory tests were performed to measure the particle shape and its relation with compactibility of base course aggregates. The full scale road structure was constructed with the 1974 NRB B/2 specifications using nine different basecourse materials. The results indicated that the shape of aggregate does not have much influence on pavement performance. The aggregate gradation was found to have a greater influence on performance, than the shape.

This conclusion was drawn by assuming no particle and moisture movement took place during the test. Moreover, the research did not consider the percentage of rounded versus angular particles in each sieve range.

The performance of the aggregates should have been observed by isolating the shape and gradation factors. In addition to this isolation, all sizes in each type of aggregate should be considered when comparing shape of aggregates. Moreover, the revised NRB Specification B/2 (1985) should be considered for the construction of full scale road structure. Thus to obtain the performance of shape and void ratio, elastic deflections and permanent deformations were measured at CAPTIF under ideal conditions.

## 1.3 Objective of the Research

The objective of the project is to examine the influence of

1. Void Ratio and
2. Particle Shape

of aggregates on the performance of thin surfaced unbound basecourse flexible pavement.

The pavement performance is influenced by many factors such as particle shape, movement of particles, moisture content and movement, subgrade CBR, compactive effort and loading condition. To isolate the effect of the shape and void ratio, other factors are to be constant during the test or have a minimal influence.

The aggregates are used only for a basecourse layer and no subbase layer is provided. This helps to isolate the influence of the aggregates on base stability.

The ultimate goal of such a project should be to incorporate the results while framing a new set of standards.

# CHAPTER II

# THEORY AND LITERATURE REVIEW

## 2.1 Introduction.

Aggregate performance depends on many factors such as shape, gradation, moisture content, compactive effort, density, cohesiveness of fines and method of placing. This chapter briefly discusses the relation between those factors and aggregate performance. The emphasis of the literature review is on the research of the shape and gradation properties related to the aggregate performance.

## 2.2 Aggregate : Roading Material

An aggregate is defined as a collection of homogeneous particles. The function of aggregate in a pavement system is to transfer and distribute stresses induced by wheel loads. An aggregate layer needs to be compatible with the adjacent layer. Aggregates are required to retain their stability throughout the design life of the pavement. The characteristics of the aggregates should also be suitable for ease of construction.

## 2.3 Factors which influence aggregate performance

The characteristics of aggregates will be influenced by a variety of factors which may or may not manifest themselves depending on the particular circumstance prevailing. The research on aggregate performance has been monitored in New Zealand since 1969 (A.D.Smith 1974). The influencing factors such as rock type, particle size distribution, confinement within the metal course, moisture sensitivity and relationship to other pavement components were reviewed and documented in RRU Bulletin No.50 (F.G.Barley 1980). The related influencing factors to this project are further discussed.

### 2.3.a Particle Shape

Particle shape can be defined on the basis of angularity number, flakiness index or the elongation index as described in B.S.812. But in practice, particle shape is classified as either angular or rounded. Angular aggregates will have angular faces which contribute to aggregate interlock and a rough surface texture which inhibits movement of one particle on another. This interlocking produces higher bearing capacity compared to rounded aggregates (Yoeh 1978). The angular aggregates requires less compactive effort to achieve maximum density.

The combination of angular and rounded aggregates offers better economical appraisal to the project if both types of material are available locally. The cost of the project is directly related to the haul distance (O'Flaherty 1974). The haul distance will be considerably less if suitable borrow pits either angular or rounded aggregates are available in the vicinity of the project. The use of both type may be justified by economical haul distance and its sutability as a roading material.

### 2.3.b Gradation

In an aggregate mass, the presence of different sizes and their percentage of the aggregate is termed as gradation. The smaller size particles will be accommodated in the voids between the larger size particles. This process is continuous from maximum size to a minimum size in the mix. It eventually produces a dense mix if uniform size and percentage of the individual sizes of aggregate are properly selected. This was initially developed by Fuller and Thomsan (Kerbs and Walker 1971). A fundamental development in this regard was introduced by Talbolt and Richard using gradation exponent `n' (Kerbs and Walker 1971).

The gradation is specified by the maximum and minimum size of the aggregate and the gradation exponent with the following relationship

$$P = (d1 / D1)^n * 100 \%$$

Where P = percentage passing the sieve size d1

D1 = maximum particle size

n = gradation exponent.

The aggregate performance depends on uniform distribution of individual size in order to produce maximum shear resistance but at the same time sufficient air voids are required in the mix to ensure permeability. The gradation envelope or curve should be such that the aggregate mass should produce maximum density. The maximum density may be achieved at gradation exponent n = 0.5. (Kreb and Walker 1971)

Bartley (1984) has documented that large (40 mm maximum) size aggregates are more rigid than those with small (20 mm maximum) size material. RRU Research Project No.BC-16A titled " Marginal aggregate pavement trials Quarry Road, Drury" (Bartley 1984) indicated that there is no difference in the performance of 40 mm and 20 mm as maximum size aggregates. The NRB M/4 specification allows use of both size as maximum size aggregates.

Another approach to the functional relationship $P = (d1/D1)^n *100\%$ was studied by Salt(1977). He related grading shape with ratio of percentage passing of consecutive two sizes in the mix. The practical application of this relationship has proven to be difficult.

The functional relationship was studied by changing gradation exponent n value from 0.4 to 0.7 and the results were documented in RRU bulletin 67 (Bartley 1984). The conclusion of the project showed that even for `marginal' aggregates ( The quality of the aggregates in some respect is less than specified in NRB M/4 1975), a stable gradation lies between 0.4 and 0.55.

Fong (1979) indicated that n=0.6 has lower stability compared with n=0.5 and 0.4. The NRB M/4 1985 specification allows a range of n values from 0.4 to 0.6

**2.3.c Cohesiveness of fines**

A dense matrix of aggregates is a result of well graded material containing just enough fines as "binder" to small voids. The binding characteristics of fines is directly proportional to it's cohesiveness. Hence the presence of cohesive fines in the aggregate mix is essential to obtain a stable mix.

**2.3.d Moisture Content**

The moisture in the mix should be controlled closely. Lesser percentage of moisture will produce an open mix while a higher percentage of water will develop plasticity within the layer. In the short term water will have a direct influence on the strength characteristics of the aggregate mass. In the long term water acts as a weathering agent. Excessive water should be drained off from the layer. The movement of desired moisture will lead to instability in the pavement structure (Bartley 1980).

The major engineering properties:- density and moisture content are almost synonymous. This generalisation has its limit. It tends to breakdown with high water content.

**2.3.e Compaction**

Basecourse aggregates when compacted, gain strength by friction between the contact points of the aggregates. As compaction proceeds, the contact points of particles increases, resulting in decreased air voids in the mix. Thus zero air voids material will have maximum contact points resulting inoptimum density. Further compaction will lead to rolling of particles, and air voids will again develop within the material termed as dilatancy. Therefore compactive effort should be such that material should reach its maximum density and at the same time dilatancy should not develop.

The degree of contact depends on water content and type of compactive equipment.The compactive effort can be classified into four types viz. static, kneading, impact and vibrative. Depending upon the type of material compactive effort can be applied proportionally. The selection of type of equipment is also related to the basecourse material and its density. For example, NRB B/2 Specification specifies a maximum number of passes of a particular type of equipment with a given load and frequency. The effect of compaction on the basecourse layer depends on engineering properties such as density, elastic shear stiffness, shear strength, angle of friction, permeability and the equilibrium of saturation ( Thom and Brown, 1987).

### 2.3.f Segregation

The placing of aggregates should be done carefully. Dropping the material more than 1 m will lead to segregation i.e. fine particles will be separated from the coarser particles which will produce an accumulation of the same size particles at different locations. A localised deformation will be the response from the pavement structure due to the segregation.

## 2.4 Pavement Thickness Design

Pavement thickness design is concerned with the determination of an optimum combination of materials to meet the requirement of particular situation. In establishing the depth of each layer, the aim is to provide the minimum thickness of material that will reduce the stress on the covered layer to within its load carrying capacity.

Flexible pavements are generally designed by the method `Multilayer Elastic Theory'. This analytical method has two limiting criteria: a vertical compressive strain or horizontal tensile strain. For unbound granular aggregate pavements with thin seal surfacing vertical compressive strain is a limiting criteria. The combination of design variables like subgrade CBR, loading and the thicknesses of layers can be related by the charts. The design standards employed for this project are specified in the State Highway Pavement Design and Rehabilitation Manual (1987)

## 2.5 Summary

Aggregate performance depends on many factors which are related to each other; for example, compaction, moisture and density. To isolate the effect of shape and gradation (i.e.void ratio) the influencing factors such as moisture content, crushing strength of aggrgates, subgrade CBR and load were kept constant for this project.

# CHAPTER III

# DESIGN AND CONSTRUCTION OF TEST PAVEMENT

## 3.1 Introduction

This experimental study examines the performance of different gradations and different shapes of aggregates as a basecourse layer in unbound, flexible thin-surfaced road structures. Nine different samples were produced by changing the gradation exponent for angular and rounded aggregates. Combinations of angular and rounded aggregates
for the same gradation exponent were also used as test segments. This chapter deals with the structural design, materials and construction of full the scale road structures.

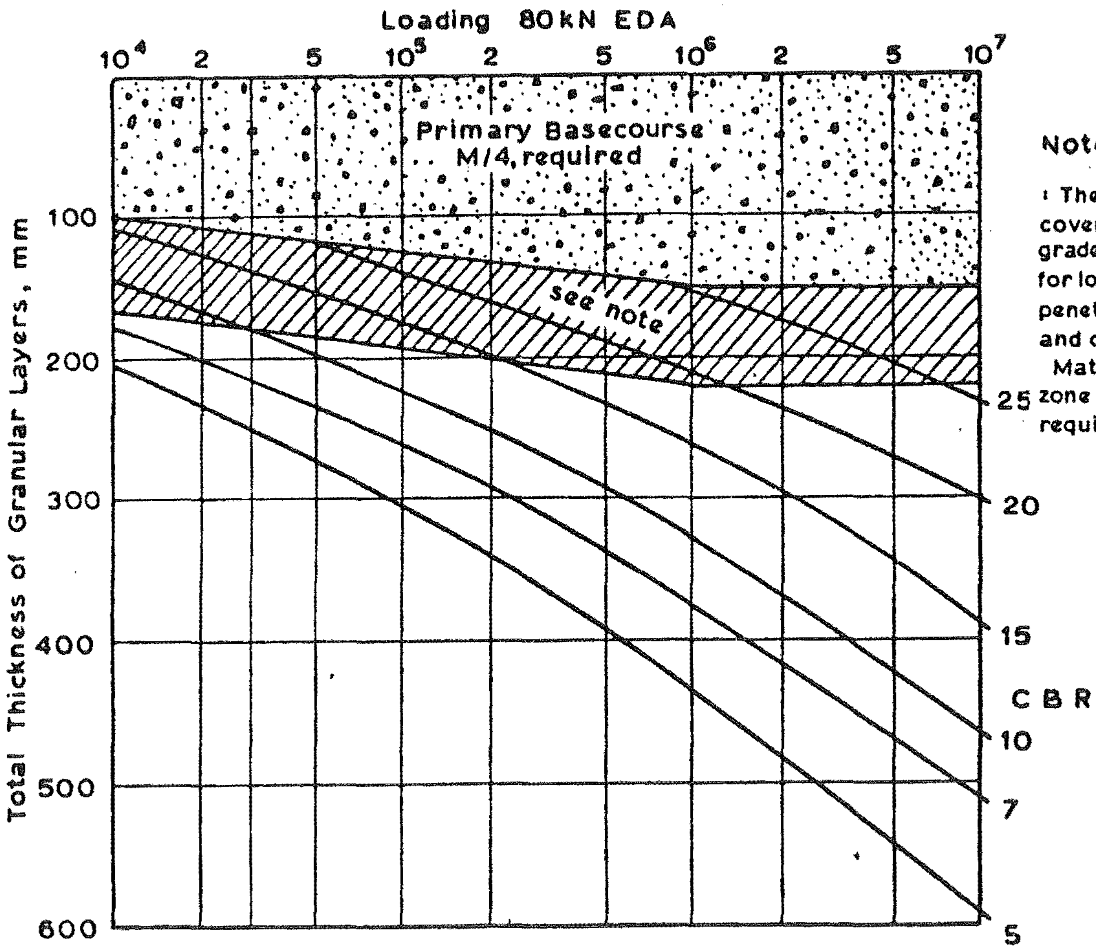
## 3.2 Structural Design and Design Loading

The project was aimed at comparing the shear resistance of each basecourse material sample. For structural design, State Highway Pavement Design and Rehabilatation Manual (NRB, 1987) was followed. Considering the main aim of the project, no subbase was provided. This ensured that the performance of the pavement was related to only the basecourse. The design chart and thickness of base course are shown in Fig.3.1.

Fong (1978) observed that for a similar basecourse material the significant difference of performance was at $2.5 * 10^5$ EDA's. The designed loading for this project was also considered as $2.5 * 10^5$ EDA's which is an optimum time of usage of the facility considering the operating costs.

### 3.2.a Subgrade

The same subgrade material was used for all segments. Uniform strength subgrade is essential to




Note

: The curves give minimum cover required above the subgrade. Allowance must be made for loss of material through penetration into soft subgrades and construction tolerances.
Materials for use in hatched zone must satisfy permeability requirements SE >40

DESIGN CHART FOR PREMIUM FLEXIBLE PAVEMENTS WITH THIN SURFACINGS

FIGURE 3.1

ensure that all the base course materials are tested under similar conditions. The subgrade material was selected so as to achieve: a> confirmation of the subgrade compaction to a desired value as per NRB Specification F/1 (1986) and b> saving of time by eliminating the removal and replacing of the subgrade material.The subgrade aggregate was placed over the existing foundation in the track, which was Port Hills loess. Scala Penetration Tests were conducted on the foundation material and the inferred CBR value was greater than 25. It was assumed that the CBR value of the subgrade aggregate was greater than 25.

### 3.2 b Geomembrane

An impermeable layer of geomembrane placed at the basecourse-subgrade interface. It was needed to restrain any possible vertical movement of moisture and fine particles. A thin (0.5 mm), flexible geomembrane composed of butynol was selected because the high elastcity, this material would not promote the development of shear plane failure at the interface.

### 3.2 c Basecourse.

With the assumed value of loading and the known value of subgrade CBR, the minimum required basecourse thickness was determined as 125 mm. The basecourse material used for the test complied with the NRB Specification M/4 (1985) with maximum particle size of 37.5 mm. Nine different types of basecourse material were used for the test segments, which are discussed in article 3.3.

### 3.2 d Friction Course

A wearing surface of friction course (NRB. P/11P, 1984) was chosen because: (i) the mix adds minimal structural capacity to the pavements, (ii) a high degree of control during placement is available, and (iii) the friction course surfacing provides a very smooth, deformable surface that permits accurate measurements of surface profiles.

### 3.3 Basecourse Material

#### 3.3.a Selection

Basecourse aggregates consisting of all angular, all rounded, and various combinations of angular and rounded particles were selected for study. The gradation envelope range for basecourse aggregates as per NRB Specifications M/4 (1985) is given in Table 3.1 and graphically presented in Fig 3.2 .

TABLE 3.1 Grading Envelope

| Test Sieve Aperture (mm) | Percentage Passing (Percent %) |
|---|---|
| 37.5 | 100 |
| 19.0 | 66 - 81 |
| 9.5 | 43 - 57 |
| 4.75 | 28 - 43 |
| 2.36 | 19 - 33 |
| 1.18 | 12 - 25 |
| 0.600 | 7 - 19 |
| 0.300 | 3 - 14 |
| 0.150 | 10 Max. |
| 0.075 | 7 Max. |

In this gradation envelope, the lower limit of the gradation envelope corresponds to the percentage passing is at the gradation exponent n=0.6 while the upper limit is 0.4. Therefore three gradation exponents were selected: n=0.4, 0.5 and 0.6. This produced three pairs of samples of 100 percent angular and 100 percent rounded aggregates. The three combinations of fractions of angular and rounded aggregates ( ie. 30 % rounded, 50 % rounded and 70 % rounded; the remainder,angular ) with constant n=0.5 were selected. The percentages, 30,50 and 70, were selected to derive any percentage of combination of angular and rounded material within the range of 30 and 70. The lower limit, less than 30 %, and

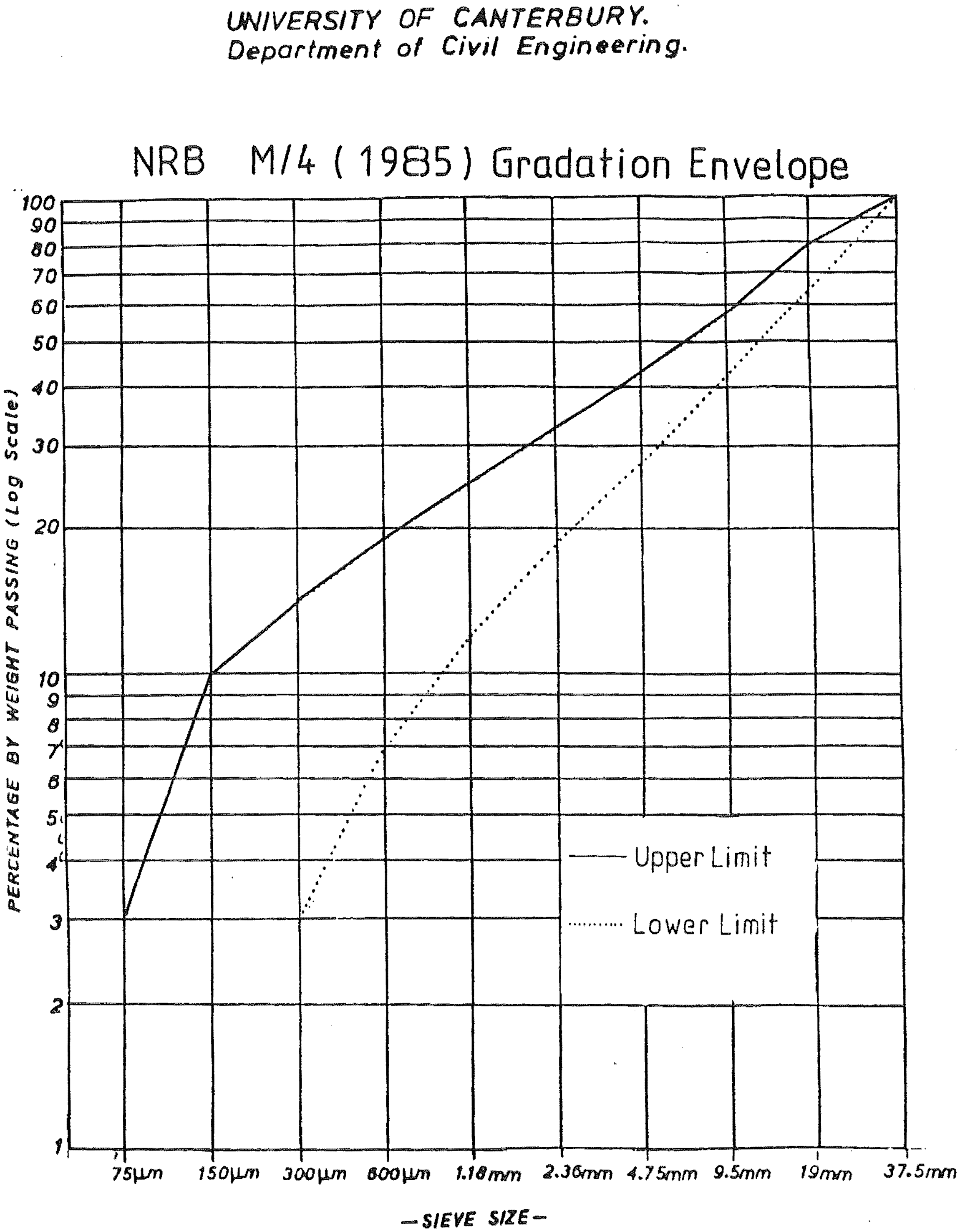

UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.
NRB M/4 (1985) Gradation Envelope
PERCENTAGE BY WEIGHT PASSING (Log Scale)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
Upper Limit
Lower Limit
75µm
150µm
300µm
600µm
1.18mm
2.36mm
4.75mm
9.5mm
19mm
37.5mm
—SIEVE SIZE—

Figure 3.2

upper limit, greater than 70%, were to be treated as approaching 0 % and 100 % respectively. Thus a total of 9 basecourse samples were selected and tabulated in Table 3.2, as `Target' gradation envelopes.

Table 3.2 `Target' Gradation Envelopes.

| | 100 % Angular | | | 100 % Rounded | | | Combination | | |
|---|---|---|---|---|---|---|---|---|---|
| Segment | D | E | F | C | B | A | G | H | I |
| `n' | .4 | .5 | .6 | .4 | .5 | .6 | .5 | .5 | .5 |
| Sieve Size | | | | | | | | | |
| 37.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 19.0 | 76 | 71 | 66 | 76 | 71 | 66 | 71 | 71 | 71 |
| 9.5 | 57 | 50 | 43 | 57 | 50 | 43 | 50 | 50 | 50 |
| 4.75 | 43 | 36 | 28 | 43 | 36 | 28 | 36 | 36 | 36 |
| 2.36 | 33 | 25 | 19 | 33 | 25 | 19 | 25 | 25 | 25 |
| 1.18 | 25 | 18 | 12 | 25 | 18 | 12 | 18 | 18 | 18 |
| 0.60 | 19 | 13 | 7 | 19 | 13 | 7 | 13 | 13 | 13 |
| 0.30 | 14 | 9 | 3 | 14 | 9 | 3 | 9 | 9 | 9 |
| 0.150 | 10 | 6 | 2 | 10 | 6 | 2 | 6 | 6 | 6 |
| 0.075 | 7 | 4 | 1 | 7 | 4 | 1 | 4 | 4 | 4 |

### 3.3.b Procurement

When a specified gradation can not be produced from the same source of aggregates, blending is required. It is a common practice that aggregates of closely graded sizes may be subsequent remixed in the desired proportion. The geological source may be different for different particle sizes. The cohesiveness may differ within the same mix. Subsequently, this may affect the performance of the aggregates. Moreover, the process of combining the aggregates is a complicated procedure. A mathematical and graphical systems for blending of aggregates from different resources is discussed by O'Flaherty (1974) and Atkins (1980).

The `Target' gradations were provided to the roading contractor. The roading contractor blended materials from various sources to meet the `Target' gradations. The same contractor procured the material,placed and compacted the pavements, and surfaced the basecourse. The contractor confirmed that the targeted gradation could be made available with minor changes. Those changes were within the range of the specifications and therefore the contractor was requested to deliver the material. To get the targeted gradation envelope, the contractor blended the material from different quarries: Hasketts Rd. quarry, Coutts Island quarry, Miners Rd. quarry and Pavroc Industries. Due to the blending required for each type, delivery of material was delayed by 6 weeks.

### 3.3 c Laboratory Tests

To avoid further delay in the project, the material delivered on site was immediately placed in the test segments. Meanwhile the following laboratory tests were carried out:

a > Sieve Analysis : This test was carried out before and the end of experiment as per NZS 4402 : 1986 test 2.8.2 and the results are tabulated in Appendix E.

b > Optimum Moisture Content: This test was conducted as per NZS 4402 part 2 2P 1980 test No.14 for all test material. Appendix E containts graphs of the moisure content versus density relationship.

c > Shape of aggregates: Shapes were identified by close visual inspection of representative samples.

## 3.4 Construction

The construction was carried out according to NRB Specification B/2 (1985). The track was divided into nine equal segments of 6 m each, as shown in fig.3.3.a .

### 3.4.a Subgrade

The existing subgrade material was aggregate with a maximum particle size of 65 mm, and was removed to a depth of 150 mm . The same material was relaid and uniformly compacted with a 3 t roller. The static and vibrating loading was carried out for 2 passes each. The top of the subgrade material was kept 150 mm below the concrete face of the wall to accommodate a uniform thickness of the basecourse layer. Densities were monitored for each segment.

The uniform strength of the subgrade throughout the test track was confirmed by measuring densities at the centre of each test segment as shown below.

Table 3.3 Subgrade Density

| Segments | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| Density ($Kg/M^3$) | 2190 | 2160 | 2000 | 2210 | 2250 | 2210 | 2280 | 2220 | 2240 |

The profiles were measured by straight edge. At the centre of each segment the straight edge was placed on the top of a concrete wall and the depth to the subgrade was measured every 200 mm. After the experiment the subgrade profiles were measured by the same method. The initial and final profiles are given in the Appendix E. A compacted subgrade material is shown in Plate 1.

### 3.4.b Geomembrane

The geomembrane used in this project was 0.5 mm Dunlop Butynol sheeting. The geomembrane was laid in a transverse direction to wheel movement. A minimum 100 mm overlap was maintained to avoid slippage of the membrane during construction and applied loading. Geomembrane sheets were extended up to the face of the concrete side walls to avoid migration of moisture through the sides. The placing of geomembrane is shown in Plate 2.

### 3.4.c Basecourse

All nine types of basecourse material were stockpiled separately on the outdoor,concrete pad near the track. As soon as the material was received on site, it was placed immediately to avoid any loss of fine particles or any contamination.

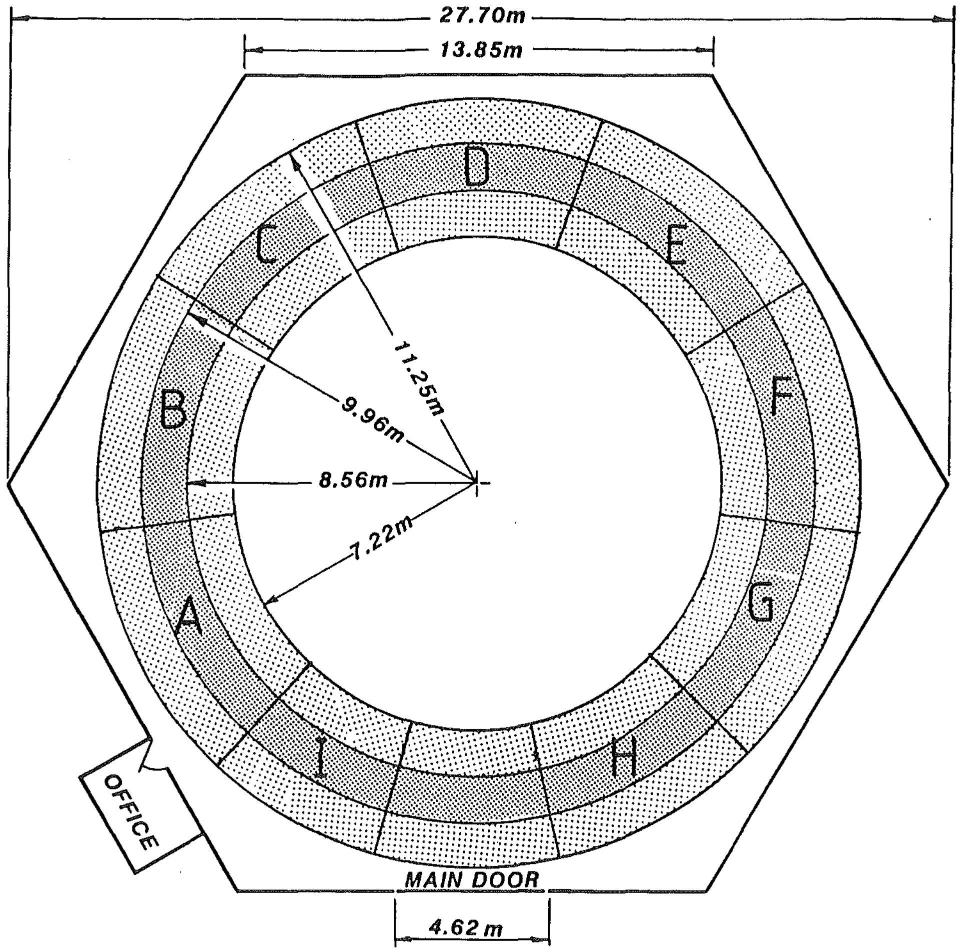
The track layout is shown in fig. 3.3 a. Only three sheets of geomembrane 1000 mm wide each were laid initially to avoid disturbance by the loader. The placing of the material from the stock pile was done by loader. The height of drop of the material was kept as low as possible ( max. 300 mm) to avoid segregation while placing. The material was levelled by hand racking and the levelling was checked by straight edge. As the placing of material proceeded, the remaining geomembrane was laid. A removable partition was used to separate the segments during placement of the aggregates, to avoid mixing of materials. The placing of material by loader, the wooden partition and the straight levelling edge is shown in Plate 3.

The placing of material was started from segment C (Station No.18), and segments D,B,E,A,F,I,G and H completed in sequence. A 4 m. length of the track (Stn.48 - Stn.52 ) was not used for test material because it was adjacent to the main entrance, and access to the track was over this section. Basecourse material (NRB Specification M/4, 1985) was placed between Station.48 and 52 for continuity of the basecourse layer.

### 3.4.d Compaction

To add sufficient water for compaction and to spray the water uniformly a perforated pipe was initially tried. The quantity through this sprinkler system was insufficient and therefore this method was abandoned. The water was sprayed manually with care to achieve uniform distribution. The initial spray was just sufficient for compaction needs.

The compaction was started with a self- propelled vibrating roller. The centrifugal force for this vibrating roller at high and low amplitude is 155 kN and 78 kN respectively, while the static force is 40 kN ( Plate 4 ). An equal compactive effort (i.e. equal number of passes ) was given to all nine segments. Moisture




Segment Layout (Initial)

Figure 3.3.a

content and density at the centre of all the segments were monitored for each pass by nuclear densometer. Water was uniformly spread during the compaction.

The material was placed to a depth of 125 to 150 mm thick. Table 3.4 shows the compacted thickness for different segments.

Table 3.4 Thickness of Basecourse

| Test Segments | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Compacted Thickness (mm) | 108 | 110 | 115 | 110 | 103 | 114 | 101 | 104 |

The compaction was monitored by recording the density of each segment after each pass of the roller. The density versus number of passes relationship is plotted in Appendix C. As a ready reference, a typical graphical representation is shown below. It was noted that the contractor's crew and overseer were unfamilier with this practice of checking the density after each pass of the roller, though they were referred to by the contractor as " one of their most experienced teams".

While monitoring the density it was observed that the densities of segments D,E,F,G and H were increasing while, those of segments C,B,A and I were decreasing. After six passes of vibrating static force was applied but the same results continued. After two passes of static roller, the condition of segments C,B,A and I became that of total loose material. A pneumatic 7 tyre, 7 tonne roller was used to compact the C,B,A and I segments. The results were still worse. Shoving developed. The deformation in the segment I is shown in Plate 4. The roller sunk in the basecourse material. Therefore at this stage it was decided to remove segments C,B,A and I from the testing.

Seddon (1988) indicated that in order to produce a dense compacted mix for Research Project No.BC-19 (Yeoh, 1978) additional crushed fines were added.

### 3.4.e Modifications

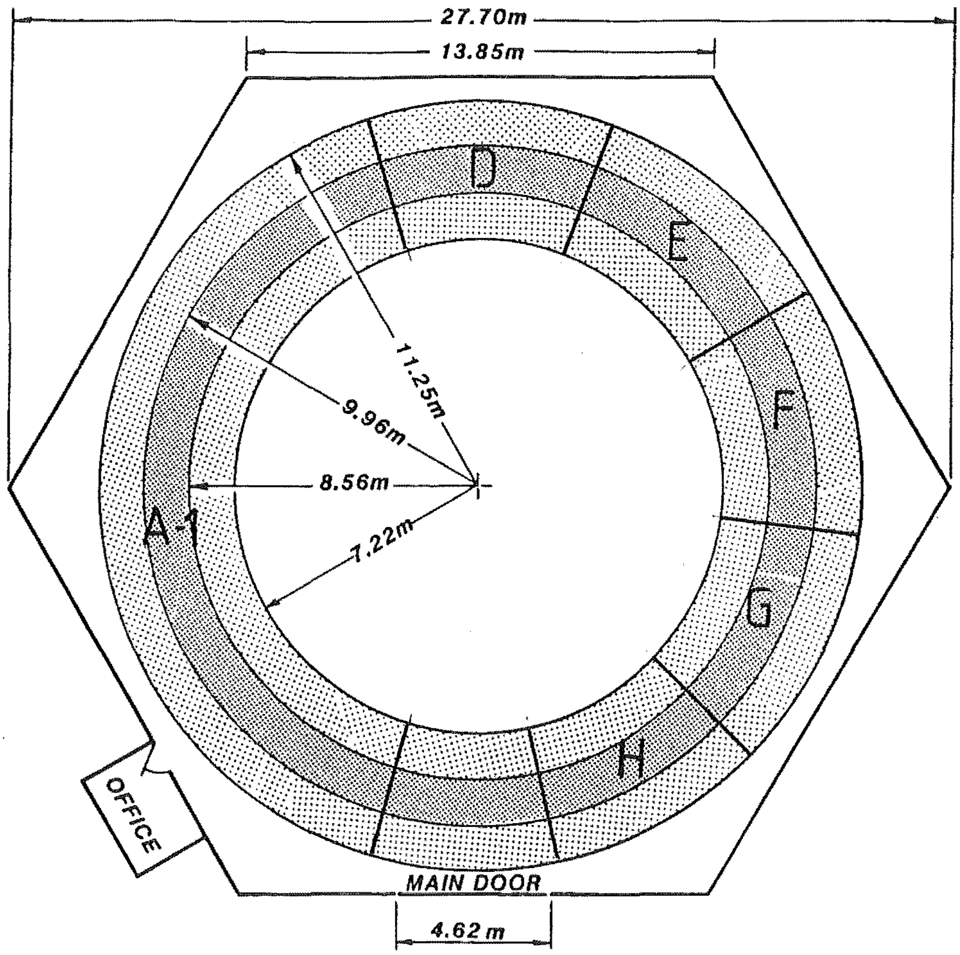
The basecourse material of segments C,B,A and I were removed carefully, so as to save the geomembrane. To continue the test, 100 percent rounded material (Christchurch - M/5 ) was used to replace the segments and is designated as the A-1 segment in further discussion. The same geomembrane was laid after the inspection of subgrade profile. A-1 segment material was placed in the track directly from the truck. The material was levelled in similar manner to the earlier method.

A-1 material had sufficient water content for compaction, hence no additional water was spread. The 2 ton, 2500 vibrating frequency roller was used for a total of four passes. This compactive effort was restricted to only the A-1 segment.

Then, in the final stage of primary compaction two passes of the pneumatic tyre roller was used over all segments. The circular shape of the test track restricted the use of the pneumatic tyre roller. Seven passes of the static roller completed this compaction phase.

A minor modification was carried out for the segment F when the surface showed an open mix over about 60 % area. Hence approximately 0.8 $M^3$ crushed quarry dust of 5 mm was sprayed over an area of 14 $M^2$. This segment was compacted with 1 ton vibrating roller for six passes. A revised layout of test segments with these modifications is shown in Fig. 3.3.b .

To achieve initial loading, two passenger automobiles were driven at 15 km/h. around the track with uniform distribution over all the segments for 250 revolutions. Plate 5 shows trafficking over the test pavement.




Segment Layout ( Modified )
Figure 3.3. b

### 3.4.f Friction course.

A prime coat of hot bitumen ( 60 % bitumen and 40 % kerosene ) was applied at 0.6 $l/M^2$ on the surface and was left for two days before the friction course was laid. A bituminous mix with 5.5 percent bitumen content was laid with the paver. A uniform thickness of approximately 50 mm was maintained. Static and vibrating roller of 2 ton was used for two passes each in final compaction.

## 3.5 Summary

In the design, NRB's standard design procedure was followed. Basecourse material was selected in order to yield different shapes of aggregate and gradation envelopes. A geomembrane was used to remove any effect of moisture and fines migration on the stability of the pavement.

During the construction, the present NRB B/2 (1985) specification was strictly followed. A uniform strength of subgrade throughout the track was achieved. Basecourse material was placed by the loader to avoid segregation. The compaction was continuously monitored. Rounded aggregate segments could not be compacted; those segments were replaced by another rounded aggregate material. As a final consolidation of the pavement, cars were used to traffic the pavement. The pavement was sealed by a prime coat followed by a thin bituminous mix wearing course.

# CHAPTER IV

# TESTING ROUTINE

## 4.1 Introduction.

This chapter contains a description of the testing routine measurements and observations. The loading was continued until a significant difference in the performance of the various segments was noticed. The moisture content, densities, surface profiles and elastic deflections of the basecourse and subgrade were measured. The Profilometer, Densometer and Benkelman Beam were used for in situ testing at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF). Sieve analysis of granular samples was carried out at the University's Highway Engineering laboratory.

## 4.2 Procedure

A recording method was established to document the observations. For this investigation, a procedure was established as follows:

i> Sieve analysis of a sample of the basecourse material before and after the experiment.

ii> Monitor density and moisture content of subgrade and the basecourse layer.

iii> Measure deflections and profiles at 0 EDA, 1000 EDA's and then after every 10,000 EDA's until significant difference in performance is observed.

iv> Determine moisture content of the basecourse and subgrade at the end of experiment.

## 4.3 Facility.

The Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) contains an innovative machine that was designed for accelerated testing and evaluation of road formations, substrate's and surfacings by replicating, the effect on the pavement of actual road traffic conditions. The physical characteristics, loading system and control systems of CAPTIF are discussed in the Appendix A.

## 4.4 Loading

For this project, the total design loading was selected to be 2.5 $*10^5$ EDA's. The two vehicles (single axle, dual-wheel configuration ) of the machine were loaded to 40 kN each, representing 1 EDA. Thus in one revolution, the machine was producing 2 EDA's. Vehicles A and B were fixed with dual bias and dual radial tyres respectively, to represent a mix of tyre types found on the roads. The radial movement of 500 mm on the either side of the arm offers multiple wheel path loading which was used to simulate real traffic conditions.

### 4.4.a Load Distribution

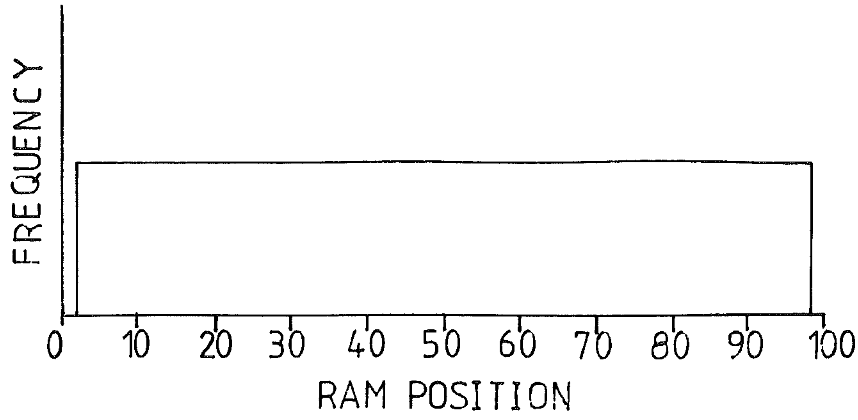
The initial load distribution was carried out at 20 Km/h. This speed was continued for the first 2,000 EDA's, in order to satisfy NRB Specifications B/2 (1985). Across the full trafficked width, the arm position was changed every two revolutions. This initial conditioning was completed with uniform distribution of loading.

After the conditioning, the speed of the vehicle was increased to 40 Km/h. The load distribution pattern was also changed from uniform to gaussian type. In this type of distribution, the frequency of the arm position at the centre of the trafficked width was higher than at the sides. Uniform and guassian type load distributions are shown in fig.4.1 .

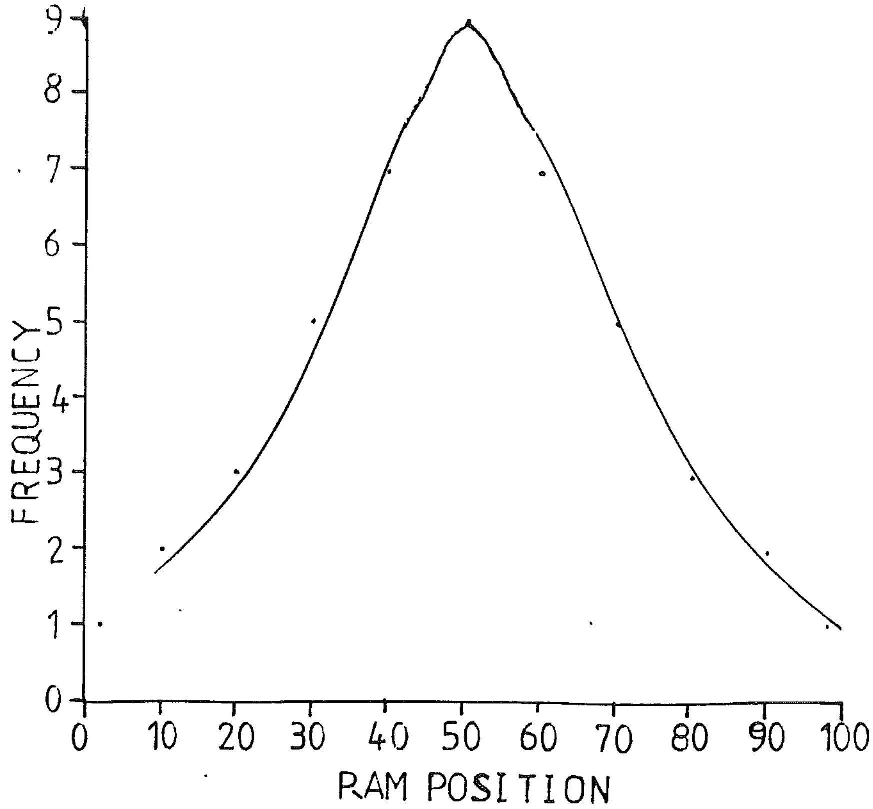
## 4.5 Pavement Performance Monitoring

The pavement performance was monitored observing density, moisture content, deflections and rut depths by

# Load Distribution Patterns




Rectangular




Guassian

Figure 4.1

nuclear density meter, Benkelman Beam device and Profilometer respectively.

### 4.5.a Density and Moisture Content

In this project, subgrade density and the density achieved during compaction of the basecourse layer were measured by the Densometer documented in section 3.4 a and 3.4 d respectively. The moisture content for the basecourse layer was also recorded by using the same device. The moisture content was recorded for the basecourse layer just before surfacing sealing the pavement and after the experiment. These results are given in Table 4.1 .

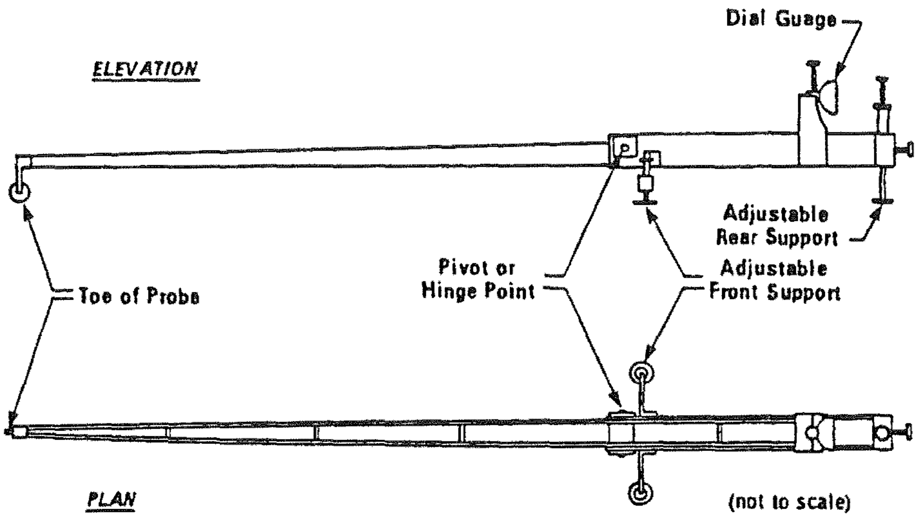
Table 4.1 Basecourse Moisture Content

| Test segments | A1 | D | E | F | G | H |
|---|---|---|---|---|---|---|
| Moisture content.before | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Moisture content. after | 3.6 | 2.7 | 2.7 | 2.4 | 2.9 | 2.2 |

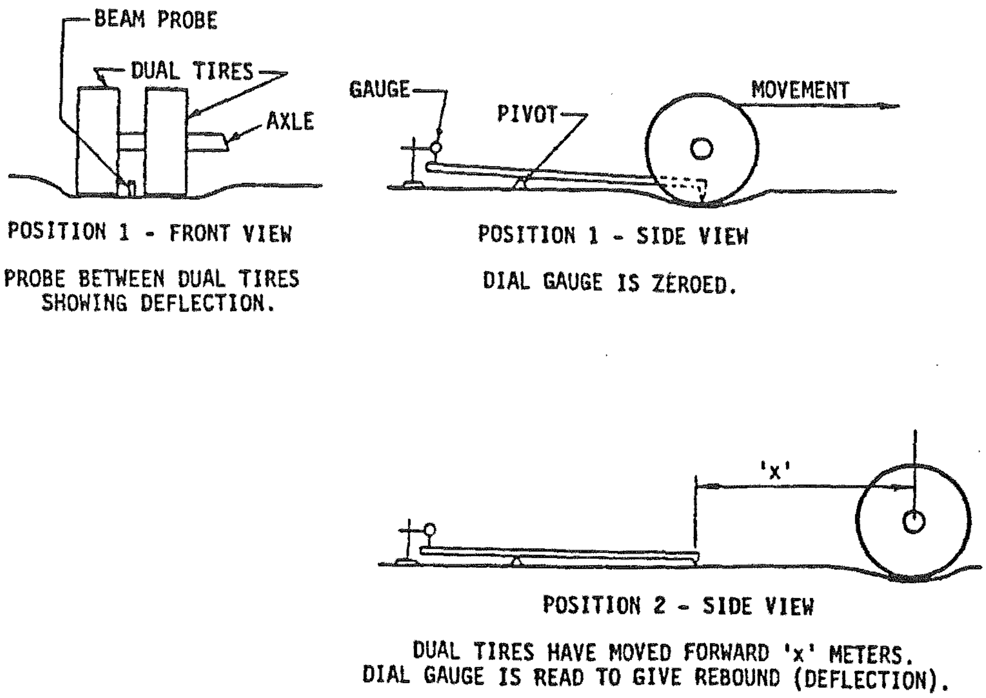
### 4.5.b Deflections

Benkelman Beam device measures elastic deflections of the pavement;temporal changes in the deflections are related to changes in the pavements' structural capacity. An advantage of this device is that it is a non.destructive test. The device is schematically shown in Fig 4.2 .

The Benkelman Beam testing was conducted according to NRB specification T/1 (1977). For this investigation, the deflection was measured at three stations in each segment. The test was done at the centre of the trafficked path. The observation points in a typical segment are shown in the Fig 4.3 . The observations are documented in the table are tabulated in Table 4.2 .




Benkelman Beam Device




Measuring Rebound Deflection with Benkelman Beam

FIGURE 4.2

Table 4.2 Deflections

| Stn. | Number of Loading: (EDA) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 2000 | 12900 | 23600 | 32100 | 43400 | 54300 |
| | | | | Segment A 1 | | | |
| 0 | 0.84 | 1.24 | 1.36 | 1.28 | 1.30 | 1.32 | 1.32 |
| 6 | 1.06 | 1.16 | 1.02 | 1.26 | 1.14 | 1.20 | 1.16 |
| 12 | 1.24 | 1.28 | 1.26 | 1.34 | 1.36 | 1.36 | 1.24 |
| | | | | Segment D | | | |
| 19 | 1.60 | 1.56 | 1.62 | 1.52 | 1.36 | 1.46 | 1.42 |
| 21 | 1.70 | 1.72 | 1.76 | 1.70 | 1.54 | 1.76 | 1.60 |
| 23 | 1.50 | 1.34 | 1.02 | 1.22 | 1.40 | 1.50 | 1.24 |
| | | | | Segment E | | | |
| 25 | 1.46 | 1.62 | 1.68 | 1.48 | 1.64 | 1.46 | 1.68 |
| 27 | 1.40 | 1.36 | 1.48 | 1.60 | 1.54 | 1.46 | 1.62 |
| 29 | 1.14 | 1.30 | 1.30 | 1.10 | 1.22 | 1.14 | 1.26 |
| | | | | Segment F | | | |
| 31 | 1.42 | 1.46 | 1.38 | 1.54 | 1.56 | 1.50 | 1.56 |
| 33 | 1.18 | 1.12 | 1.08 | 1.12 | 1.14 | 1.22 | 1.30 |
| 35 | 1.04 | 1.02 | 1.02 | 1.08 | 0.98 | 0.88 | 1.16 |
| | | | | Segment G | | | |
| 37 | 1.26 | 1.18 | 1.20 | 1.28 | 1.36 | 1.06 | 1.28 |
| 39 | 1.18 | 1.12 | 1.22 | 1.24 | 1.12 | 1.40 | 1.28 |
| 41 | 1.14 | 1.10 | 1.14 | 1.08 | 0.96 | 1.20 | 1.30 |
| | | | | Segment H | | | |
| 43 | 1.14 | 0.98 | 0.98 | 0.96 | 0.78 | 0.94 | 0.94 |
| 45 | 1.24 | 1.22 | 1.34 | 1.32 | 1.20 | 1.18 | 1.46 |
| 47 | 1.84 | 1.78 | 1.56 | 1.84 | 1.82 | 1.54 | 1.96 |

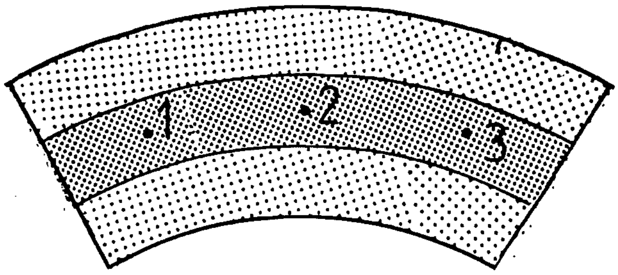
**4.5.c Vertical Deformations**

The permanent vertical deformation is an indicator of the degree of compression of the pavement's layers. The compression is related to the aggregate performance. The vertical deformation is effectively measured by the profilometer. The Profilometer and X-Y plotter used to record profiles are shown in Plate 6.

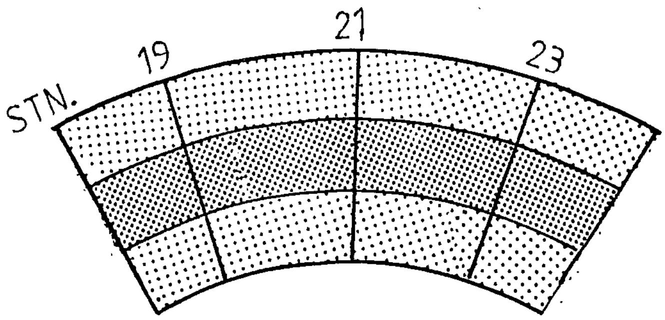
The beam end supports were kept at the exact location of each required station. The carrier's position was moved to the inner face of the track in order to establish datum. As the carrier travelled from inner face to outer face, the profile was recorded on the chart recorder.

The CAPTIF profilometer was used for the first time for this project. A full scale calibration was

Observation Points




Segment
Deflections




Segment
Vertical Deformations

Figure 4.3

carried out before it was used. The profiles were measured at three locations for each segment as shown in Fig.4.3. A typical surface profile is shown in Fig.4.4. The centreline rut depths were measured from the surface profile chart which are given in Table 4.3 .

Table 4.3 Centreline Rut Depths

| Load (EDA's) | Segment A1 | D | E | F | G | H |
|---|---|---|---|---|---|---|
| | Centreline Rut Depths (mm) | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2000 | 4 | 6 | 8 | 5 | 7 | 3 |
| 12900 | 6 | 12 | 13 | 9 | 11 | 5 |
| 23600 | 7 | 16 | 19 | 11 | 14 | 7 |
| 32100 | 8 | 19 | 21 | 14 | 19 | 9 |
| 43400 | 10 | 21 | 25 | 16 | 23 | 10 |
| 54300 | 12 | 25 | 36 | 18 | 28 | 14 |

At the end of the test, thickness of the friction course was measured at the centre of each segment. The thicknesses at 0 and 54300 EDA's are tabulated below.

Table 4.4 Thickness of Friction Course

| Segments | A1 | D | E | F | G | H |
|---|---|---|---|---|---|---|
| Thickness at 0 EDA | 48 | 54 | 51 | 45 | 45 | 42 |
| Thickness at 54300 EDA's (mm) | 45 | 49 | 45 | 40 | 38 | 35 |

The results and observations are discussed in the next chapter.

# CHAPTER V

# OBSERVATIONS AND DISCUSSION

## 5.1 Introduction.

Information obtained from the testing program is presented and discussed in this chapter. The influence of the shape of aggregate and the void ratio is examined by analyzing and comparing several indicators, such as density, permanent vertical deformation, deflections and compactive effort.

## 5.2 Subgrade

Referring to section 3.4 a and Table 3.3, density results indicated that all segments of the basecourse were supported by subgrades of equal density. Hence it is assumed that all segments were tested under a uniform subgrade condition.

There are differences in the initial and final profiles of the subgrade for all the segments as given in Appendix E. The differences were within the range of 5 to 15 mm. This deformation was consistent across the test segments.

## 5.3 Friction Course

The differences between the initial and final thicknesses of the friction course were within the range of 3 to 7 mm ( Table 4.4 ). This deformation within the surface wearing course had a negligible effect on the pavement performance.

## 5.4 Geomembrane.

The geomembrane was carefully removed after the test. For all the test segments, the geomembrane was perforated. The perforation was observed only below the trafficked path. The perforations covered about 80 percent of the area for the segments D,E,and F while for the segments G and H it was 60 to 70 percent. The perforation in the segment A-1 covered only 40 percent of the area. This was due to the 100 percent angular particles present in the D,E, and F, while A-1 had rounded particles.

The perforations may have permitted a small change in the moisture content of the basecourse material, when comparing its percentage before and after the test. The comparison is tabulated in Appendix E . The basecourse layer was sealed by the prime coat and the friction course. But the sealing can not be done near the concrete walls of the test track due to the limitations of the paving equipment. This 250 mm wide strip near the walls was all around the track. The moisture may have been absorbed by the basecourse material through this open strip. However, moisture content measurements were taken using nuclear density meter and not with a standard laboratory method. The laboratory equipment was not available at the test track.

A negligible increase in moisture content was observed for all the test segments. Therefore when performance of aggregates is compared, a similar condition existed for all the segments. The second aim of using the geomembrane was to restrain fine particles. As discussed later, this was also effective.

## 5.5 Placement of Material.

At the 26,000 EDA's loading, ruts developed between stations 16 and 17 in the A-1 segment. The bulging was 170 mm above the datum which required repair work between Stations 16 and 17 before the test recommenced. The deflection and rut depth were compared with 0 loading as documented in Table 5.1.

Table 5.1 Comparison of Deflection and Rut Depth

| Loading (EDA) | Deflection (mm) | Rut depth (mm) |
|---|---|---|
| 0 | 1.28 | 0 |
| 26000 | 1.34 | 7 |

Rut depths developed for other segments at this loading were to the extent of 19 mm but no bulging was developed in any of those segments. When the friction course was removed, localised segregation was observed as shown in Plate 7 . The development of bulge was due to the segregation, and directly related to placement of material.

## 5.6 Compaction of Basecourse layer.

The material was placed to a depth of 100 to 125 mm thick. The compacted thickness for each segments is tabulated in the Table 3.4. The compaction was monitored by recording the density of each segment on each pass of the roller. The density versus number of passes relationship is tabulated in Table 5.2 .

Table 5.2 Relation of Density and Compaction

| Material | Grad. Expn. `n' | Seg. | Density $Kg/m^3$ Roller Passes (Static) 1 | 2 | 4 | 6 | 8 |
|---|---|---|---|---|---|---|---|
| 100% Rnd. | 0.6 | A | 2010 | 2040 | 2100 | 2080 | 2060 |
| 100% Rnd. | 0.5 | B | 2050 | 2060 | 2120 | 2040 | 2060 |
| 100% Rnd. | 0.4 | C | 1990 | 1990 | 2030 | 2030 | 2070 |
| 100% Ang. | 0.4 | D | 1810 | 1910 | 1950 | 1990 | 1930 |
| 100% Ang. | 0.5 | E | 1850 | 1880 | 1900 | 1960 | 1990 |
| 100% Ang. | 0.6 | F | 1790 | 1770 | 1830 | 1930 | 1920 |
| 50%R+50%A | 0.5 | G | 1990 | 2040 | 2050 | 2110 | 2080 |
| 70%R+30%A | 0.5 | H | 1940 | 1990 | 2040 | 2110 | 2040 |
| 30%R+70%A | 0.5 | I | 1500 | 2060 | 2070 | 2040 | 2090 |

For the angular materials segments D,E, and F, the density increased with increased compactive effort. Segments D and F reached their plateau density after six passes. A continuous increment in density was observed for the segment E. It is indicated that for equal compactive effort segment E (n=0.5) densified more quickly than segments D and F.

The segments A, B and C (rounded material) reached their plateau density within four passes of the static roller (i.e. the strength offered at this compactive effort by the segments material was at a maximum). However, the test segments were unstable. It was observed that there were no cohesion between the particles; rather, dilatancy was developed. There may be two main reasons for this instability:

i > The gradation specified and that delivered on site was different, and

ii> To obtain the specified gradation, the required gradations were obtained by blending materials from four different sources (Quarries).

The subgrade deformation was consistent for all test segments while basecourse deformation was different for different segments. The different response from the basecourse was due to varying material within the layer. Moreover, The maximum deformation observed was 36 mm at 54300 EDA's through this pavement structure should sustain the design loading of $2.5*10^5$ EDA's. It is postulated that the results obtained during the test were exclusively due to the behaviour of the basecourse.

## 5.7 Gradation

The specified gradations (target) and gradations supplied, (actual) for the project for all nine samples are tabulated in Appendix B. A typical gradations is given in Table 5.3 and in Fig. 5.1. The sieve size and the percentage passing for target and used gradations (sieve analysis) are plotted on semilog graphs in Appendix B.

Table 5.3 Target and Actual Gradations

Segment A : Material 100% Rounded : Grad. Expn 0.6

| Sieve Size (mm) | Percetage Passing (%) Target | Actual |
|---|---|---|
| 37.5 | 100 | 100 |
| 19.0 | 66 | 77 |
| 9.5 | 43 | 50 |
| 4.75 | 28 | 35 |
| 2.36 | 19 | 27 |
| 1.18 | 12 | 22 |
| 0.600 | 7 | 13 |
| 0.300 | 3 | 5 |
| 0.150 | 2 | 1 |
| 0.075 | 1 | 0 |

Differences exist between the target and actual gradations for all nine materials. For rounded materials, the actual gradation was not as per specification but it was within the range of NRB M/4 (1985) specification, except for segment C. The material of segment I (combination of angular and rounded particles) was also outside of the specification limit.

Though there was a discrepancy in target and actual gradations for the segments A and B, actual gradation was within the range of specification. Therefore, the material should have compacted but dilatancy developed during compaction. This may be due to the lack of cohesive particles. Behaviour of segment I was also similar, probably for the same reason. Moreover, actual gradation of segment I was out of specification limit and air voids present in the material was lesser than required. As described in Section 2.3.e, there was no voids in the material and during compaction, particles started rolling over each another. Cohesionless material accelerated dilatancy further in the segment I. Segments A,B,C and I were replaced by another 100 percent rounded material (segment A-1). The new A-1 material was compacted and developed a stable condition for this segment.

The only difference between the A-1 material and the original segments A,B and C material is it's source. A-1

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Department of Civil Engineering.

Segment: G

SIEVE ANALYSIS

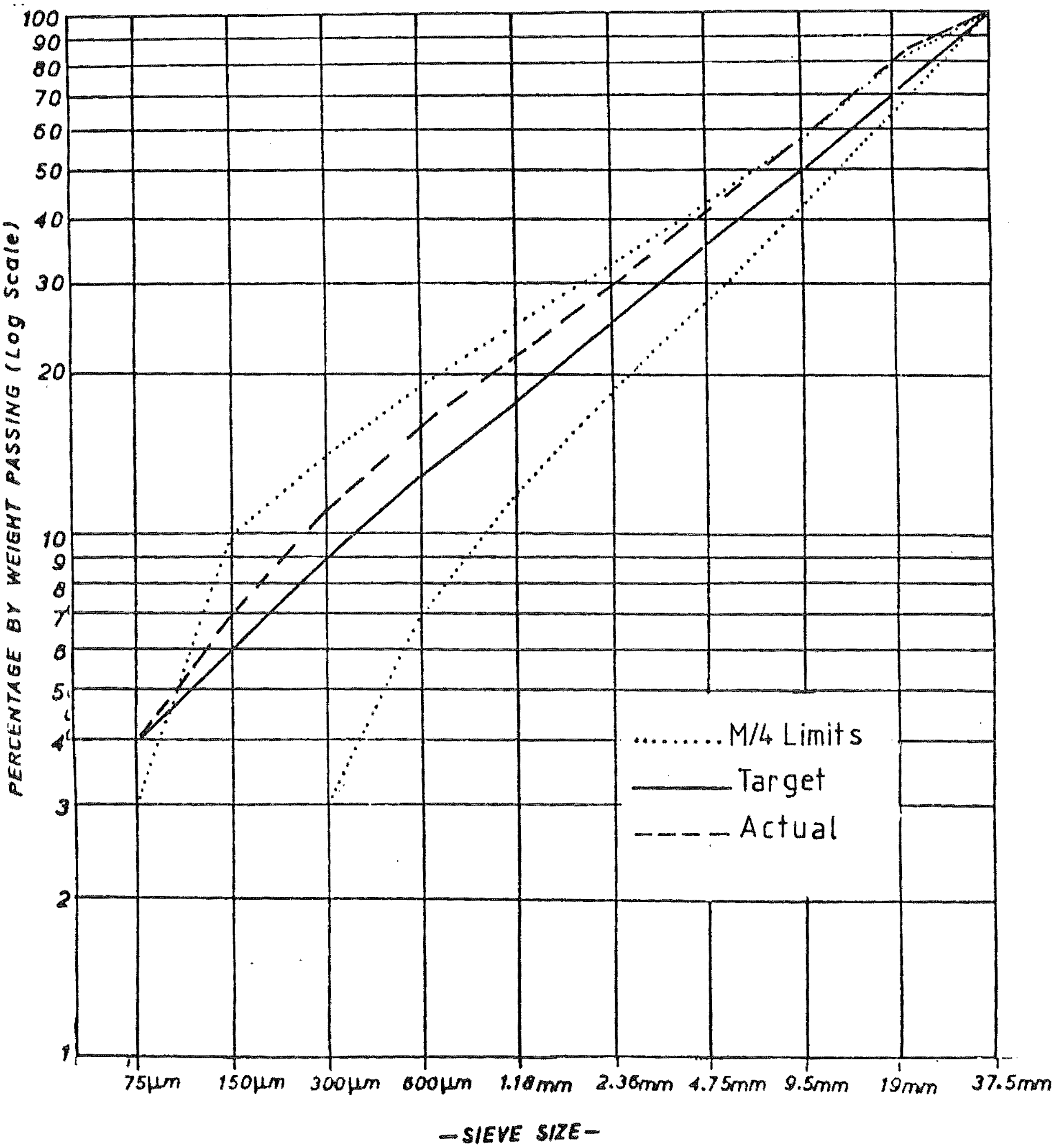


Figure 5.1

material was from only one source (Miners Road Quarry) while A,B and C materials were blended from four different quarries (including Miners Roads Quarry). It implies that fine materials have different cohesiveness of the different sources.

The particle size gradation before and after the test for all test segments are given in Appendix B. A typical gradation and its graphical representation is given in Table 5.4 and Fig. 5.1 below.

Table 5.4 Grading Envelopes

Segment G

| Sieve Size (mm) | Percentage Passing (Percent %) Before | After |
|---|---|---|
| 37.5 | 100 | 100 |
| 19.0 | 84 | 78 |
| 9.5 | 59 | 53 |
| 4.75 | 42 | 39 |
| 2.36 | 30 | 27 |
| 1.18 | 22 | 20 |
| 0.600 | 16 | 15 |
| 0.300 | 11 | 11 |
| 0.150 | 6 | 6 |
| 0.075 | 4 | 0 |

When comparing the gradation envelope before and after the experiment, the relative percentage of each particle size remained constunt for Segment A 1 while the percentage of particles smaller than 0.150 mm increased. This indicates that there was no movement nor degradation of 0.150 mm and above size material during the test in A-1 segment. The change in percentage for remaining segments may be due to degradation of the larger size particles.

For all test segments 0.075 mm size material was not present after the test. Their could be three explanations:

(i) Perforations developed in the geomembrane may have allowed the migration of 0.075 mm size material

(ii) The geomembrane was covered with fine materials and,

(iii) Sampling error.

This condition exist for all test segments, hence its relation to performance was uniform.

## 5.8 Deflections.

A measure of a pavement's response to loading may be obtained by the deflections. The performance can be related to the deflection but can not be taken alone as an indicator. However, deflections reflect the bearing capacity of the entire structure.

The first 2000 EDA's load repetitions were used to condition the surface of track. Thereafter, the deflections of the surface were measured at intervals of approximate 10,000 EDA's. This record was tabulated in the Table 4.2. The relationship between the deflections and loading graphs for all six segments are plotted in Appendix D.

The results show that exceptionally low deflections were recorded for the A-1 segments. Also the deflections were not consistent within segments. For example in segment D, the deflection at Station 19 was 1.62 mm while at 23 it was only 1.02 mm after 12900 EDA's. The deflections were not consistent even with loading. In segment E at Station 25, deflection was reduced after 12800 EDA's but again increased at 32100 EDA's. It indicates that a definite relationship between deflection and load cycles can not be achieved.

## 5.9 Deformations.

For this project, the permanent vertical deformation is the major indicator of pavement performance. The permanent vertical surface deformation, or rutting, is a result of the accumulation of unrecovered strains. The rutting is directly related to the number of load repetitions. Rutting in the basecourse layer typically produces a depression with adjacent heave or bulge. Creep distortion is reflected in the pavement depth, which often constitutes the most important failure criteria. Hence for this investigation, the evaluation of the performance is based on rut depth.

The first 2000 EDA's were treated as conditioning of the pavement structure. Thereafter, the rut depths were measured at 10,000 EDA's interval and the results are tabulated in Table 4.3.

A large increase in the permanent deformations was recorded in segment E while a small increase was recorded in the A-1 Segment. After 32100 EDA's loading, stations between segments D and E had developed rutting to only 19 mm. But the heave produced between them was greater than the clearance of the vehicles (Plate 8). A close inspection identified that an uneven surface was developed in segment D. The bouncing of vehicles caused further rutting in segment E. This stage was treated as failure of segments D and E. The bulging was removed, and an additional 20 mm thick friction course was laid on the surface in order to continue further loading.

In the next observation, at 43400 EDA's, a similar condition developed for segment G. With the addition of further loading, segments F and H also bugled. The ruts recorded at this stage were only 14 and 18 mm. At the end of loading it was observed that segment A-1 was intact, and a rut depth of only 12 mm was developed.

The first failure occurred in segment D. The gradation exponent was 0.4 of the segment D. This may have developed due to densification. The quick response to densification was due to the lower voids ratio and the degradation of larger size particle.

Referring to the actual gradation envelope of the material in segment D (Appendix B), the percentages of 19.0, 9.5 and 4.75 mm size particles was higher than targeted and even more than NRB Specifications M/4 (1985). The degradation can be justified by referring after-test gradation envelope (Appendix B) of the segment D.

During the construction stage, segment F was modified because surface texture was too open. The reason could be greater air voids (n=0.6). Crusher dust was spread on the surface where an open texture was observed. This remedy proved to be efficient when the deformation of segment F was compared with other segments.

Referring to Table 4.3 , The combinations of angular and rounded material performance studied independently. Segment G having 50 % each of rounded and angular particles had developed twice the rut depth than Segment H (70% Angular + 30% Rounded.). The actual gradation for both material was the same. Therefore the difference in performance was due to differences in the relative percentage of angular and rounded particles. An increased percentage of rounded particles may have caused more deformation. This can be further justified by the example of segment I. Segment I with 70 % rounded material would not compact at all. Referring to earlier discussion, the rounded particles were cohesionless. Increasing the percentage of rounded particles in an aggregate have a negative effect on pavement performance.

Segment C (100 % Rounded) and I (70 % Rounded + 30 % Angular ) exhibited similar behaviour. The performance of 50 percent rounded aggregates (Segment H) was different. Hence the desirable combination of rounded and angular aggregates may range between 30 to 70 percent.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

(1) Pavement behaviour was related exclusively to the basecourse layer.

(2) Placing of 100 percent rounded aggregates incurred segregation greater than other samples.

(3) The performance of aggregates was more influenced by the particles'shape than the gradation. Rounded aggregates, of similar value of gradation exponent and same blending operation as angular aggregates, could not be compacted. But the non-blended rounded aggregates required less compactive effort than did the angular particles.

(4) A significant difference was observed for the 100 percent rounded aggregates comparing its source.

(5) Aggregate performance is related to the presence of cohesive particles.

(6) It is difficult to produce a continuous gradation for a particular value of gradation exponent.

(7) For the range of gradation exponent (n) values tested, no distinct difference in performance was observed.

(8) The structural failure of the pavement can not be related with deflection observations. This may be due to the strong subgrade using a thin basecourse layer in the structure.

(9) The performance of 70 percent angular - 30 percent was better than 50 % of each type. But this can not be taken as a independent indicator because characteristics of each type of material may influence the performance.

## 6.2 Recommendations

(1) The test material should be examined for gradation exponent in the range of 0.4 to 0.45, 0.45 to 0.55 and 0.55 to 0.6 instead of.0.4,0.5 and 0.6. This will accommodate practical difficulty of obtaining gradation of the particular value of `n'.

(2) The effect of blending on the aggregate performance should be studied as a independent research project.

(3) The range of combination of percentage of angular and rounded particles should be from 30 to 70 percent.

(4) The specifications may include minimum percentage of cohesive material in the pavement layers.

(5) While designing full scale testing facility, consideration, may be given to construction machinery which may be required during projects. For example, the minimum turning radius of pneumatic tyre roller compared with the radius of track.

(6) For such investigations, where measurement of rut depth is most important a more precise profilometer (Laser beam type) may be justified.

(7) A material laboratory facility must be made available at test track. For example, an oven to check moisture content, Sieve analysis apparatus, and weigh scales are needed.

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# APPENDIX A

## Canterbury Accelerated Pavement Testing Indoor Facility

The Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) is located in Christchurch, New Zealand. In this facility, testing and evaluation of road pavements and subgrades by replicating the effect on the pavement of actual traffic conditions. In addition, a variety of tyre, axle, suspension, braking and loading systems can be tested. This facility provides test conditions which approximate field situations and characteristics of road structures.

The pavements are constructed in an annular concrete tank; the tank serves to control moisture changes and provides an absolute reference. The track is 1.5 m deep and 4 m wide, and has a median diameter of 9.26 m. The track is divisible into as many as twelve segments, so that a number of different conditions can be tested simultaneously. The facility is housed in a hexagon-shaped building 26 m wide and 6 m high.

The significant feature of this facility is its sophisticated pavement loading machine capable of applying a myriad of loading conditions via an array of vehicle types and assemblies. The machine carries a 55 kw electric motor, hydraulic pumps and reservoir, the rig-mounted electronics and various auxiliary systems. The auxiliary pump provides hydraulic power for the rams used to shift the machine's arms laterally, and for the emergency braking system.

A sliding frame within the machine's central platform is moved horizontally a maximum of 1 m, or 500 mm either side of the mid-point; this radial movement is the means by which multiple wheel paths are produced. Hinges at each outer end of the sliding frame provide for the attachment of two diametrically opposed radial arms which rotate about the fixed centre. To maintain the dynamic balance of the machine when failed pavements are rehabilitated and their surface level changes, the machine's base elevation can be altered easily by up to 150 mm.

Hydraulic output from the main pump transfers directly to the hydraulic wheel-driving motors on the vehicles affixed to the outer ends of these arms. Consequently, travelling speed is regulated by the control of this pump output. The travelling speed of the machine is variable in increments of 1 km/h up to a design maximum of 50 km/h. A standard rear axle of a truck was split and one-half of the assembly was used for each vehicle. The differential was replaced with a driving motor so that the driving force is produced at the road surface in the same manner as would a conventional vehicle. Standard wheel hubs and heavy duty truck tyres are used. Normally, braking is imposed via the hydraulic drive system, whereby the rate of braking is controlled through the main pump.

Testing can be conducted with any pair of similar vehicle types or with a different vehicle on each arm. The vehicles are designed to reproduce the road wear of vehicles ranging from light commercials to heaviest tandem axle trucks. A vehicle consists of an assembly of half- axles, wheel-driving hydraulic pumps, normal wheels and suspensions, a frame, and instrumentation. The standard vehicles are equipped with single-axle, dual-tyred wheel assemblies which can be loaded to between 21 and 46 kN. Steel weights are easily added or removed, in increments of 2.75 kN.

A differing mix of road speeds can be attained because the machine may run at a constant speed or any chosen selection of speeds for varying durations. Controlled accelerating, braking and constant speed modes are available, and can be applied to either selected segments of the track or its whole length.

Road gradients in the range of 0% to 10% may be simulated on CAPTIF's track. This condition is created by engaging a braking force that resists the rotation of the machine about its central axis. The resisting force is achieved by means of a fixed gear ring, which is mounted under the centre platform, engaged with a hydraulic pump. The premise is that a pavement laid on a slope experiences large horizontal reactions relative to the vertical reactions to wheel loads driven over it.

Testing routines are programmed in terms of a number of parameters: start/stop times, time or distance or revolutions to be run, travelling speeds, durations of constant speed, acceleration and braking, tracking pattern of wheelpath positions, and gradient angle, to name only a few. The machine's operations are directly controlled by its internal computer; but whenever a parameter is to be purposely altered, then the new command must be issued by the external personal computer via a 600- baud communications link. The machine and the computers can be safely left running by themselves. Also, the external computer can be communicated with and remotely controlled via telephone modems. Some examples of the data provided are a log of loading cycles, distances and time run, record of operating modes employed, monitored readings, fault indications, and road response. The test track is easily instrumented, and the data is acquired and manipulated by electronic systems and computers in the absence of the deleterious conditions usually found in field testing.

The Canterbury Accelerated Pavement Testing Indoor Facility was developed and is managed jointly by the National Roads Board of New Zealand and the University of Canterbury.

# APPENDIX B

## GRADATION ENVELOPES

This appendix contains a graphical representation of gradation envelopes of the test materials. Figures B 1 to B 9 show `Target' versus `Actual' gradations and Figures B 10 to B 15 indicates Gradation before (Actual) and after the experiment. As a ready reference, NRB M/4 Specification (1985) gradation limits are also shown.

UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.

Segment: A

SIEVE ANALYSIS

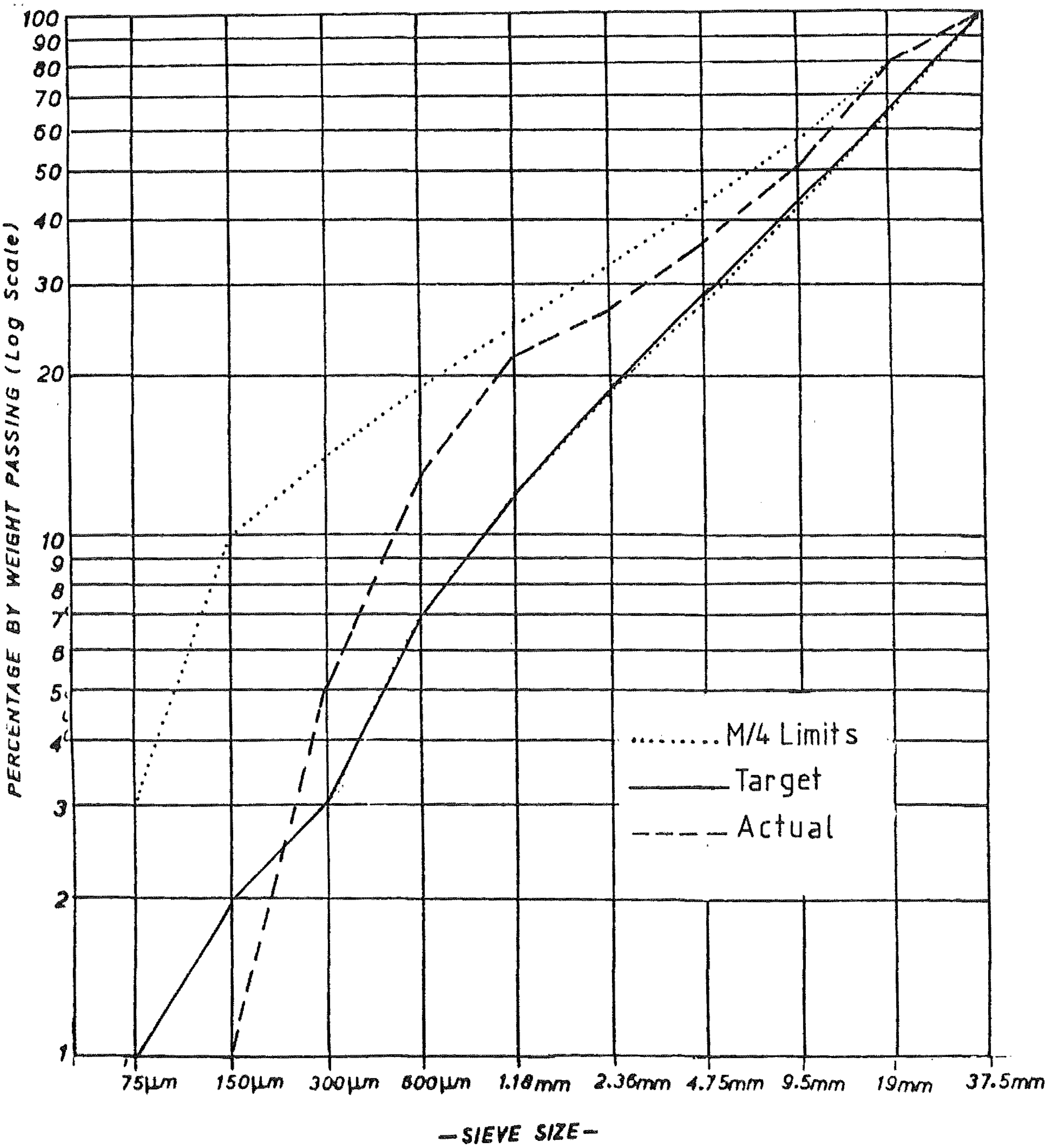


Figure B.1

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Department of Civil Engineering.

Segment: B

SIEVE ANALYSIS

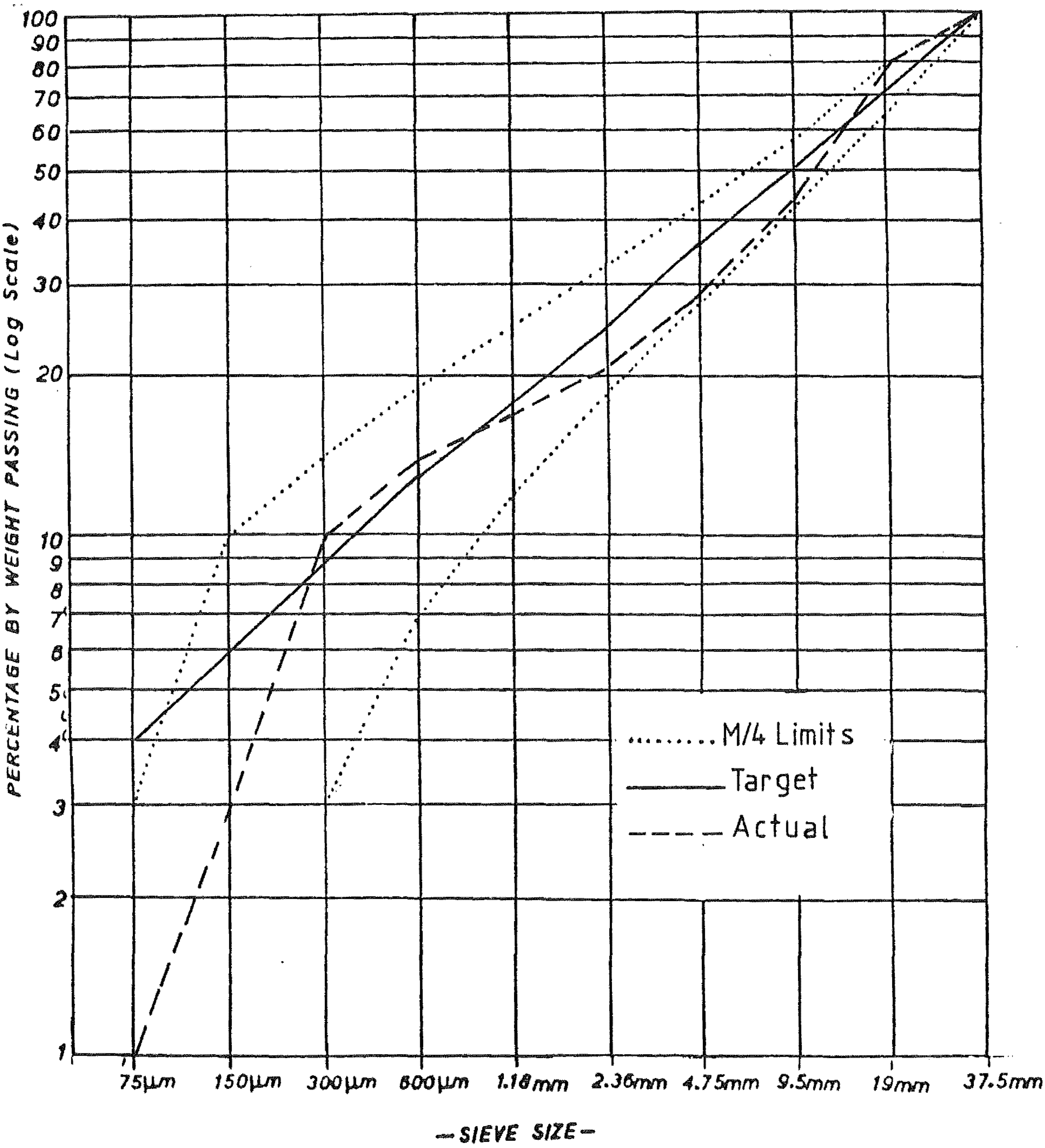


Figure B.2

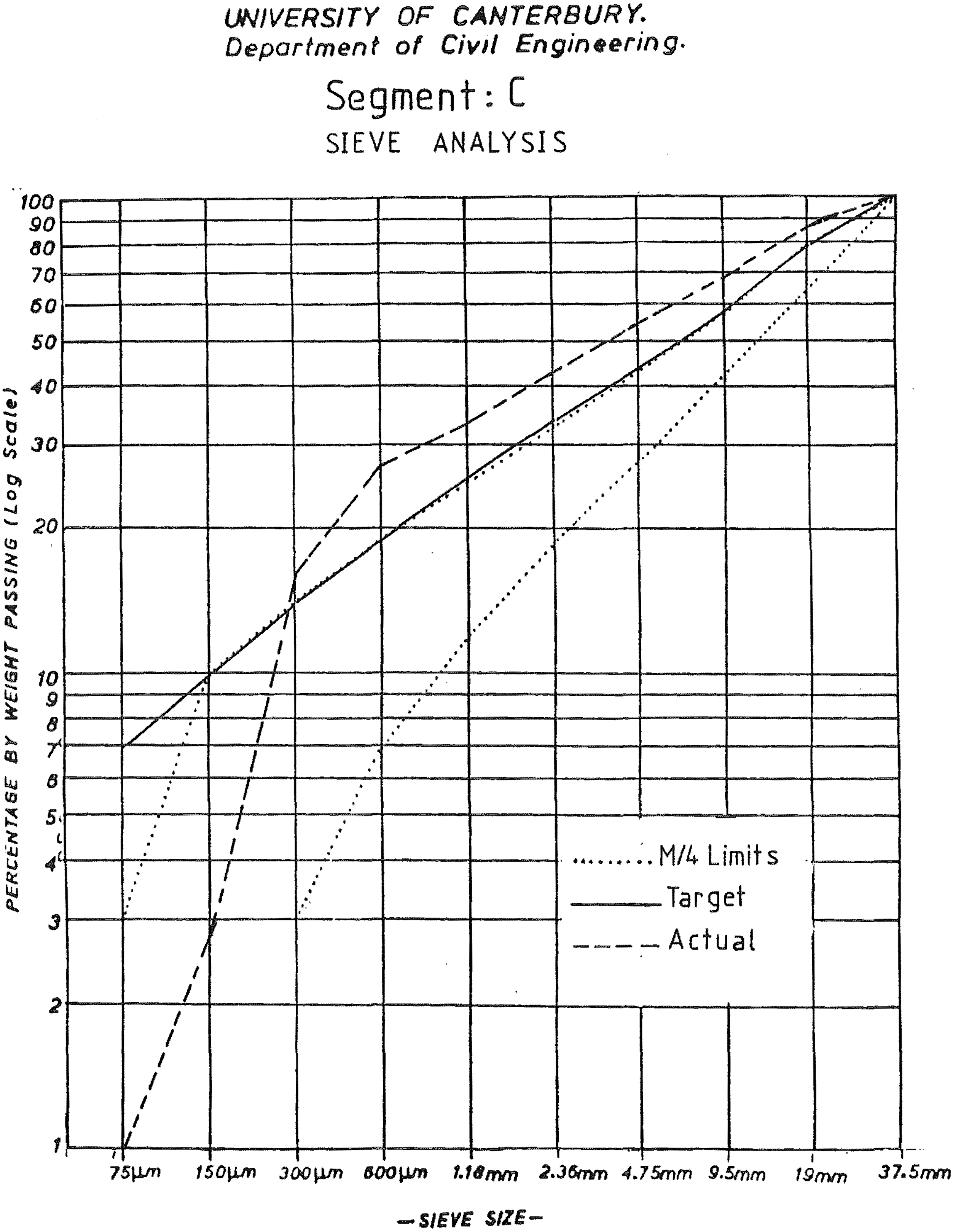
UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.
Segment: C
SIEVE ANALYSIS
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
PERCENTAGE BY WEIGHT PASSING (Log Scale)
........M/4 Limits
Target
Actual
75µm
150µm
300µm
600µm
1.18mm
2.36mm
4.75mm
9.5mm
19mm
37.5mm
—SIEVE SIZE—

Figure B.3

UNIVERSITY OF CANTERBURY.
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## Segment: D

SIEVE ANALYSIS

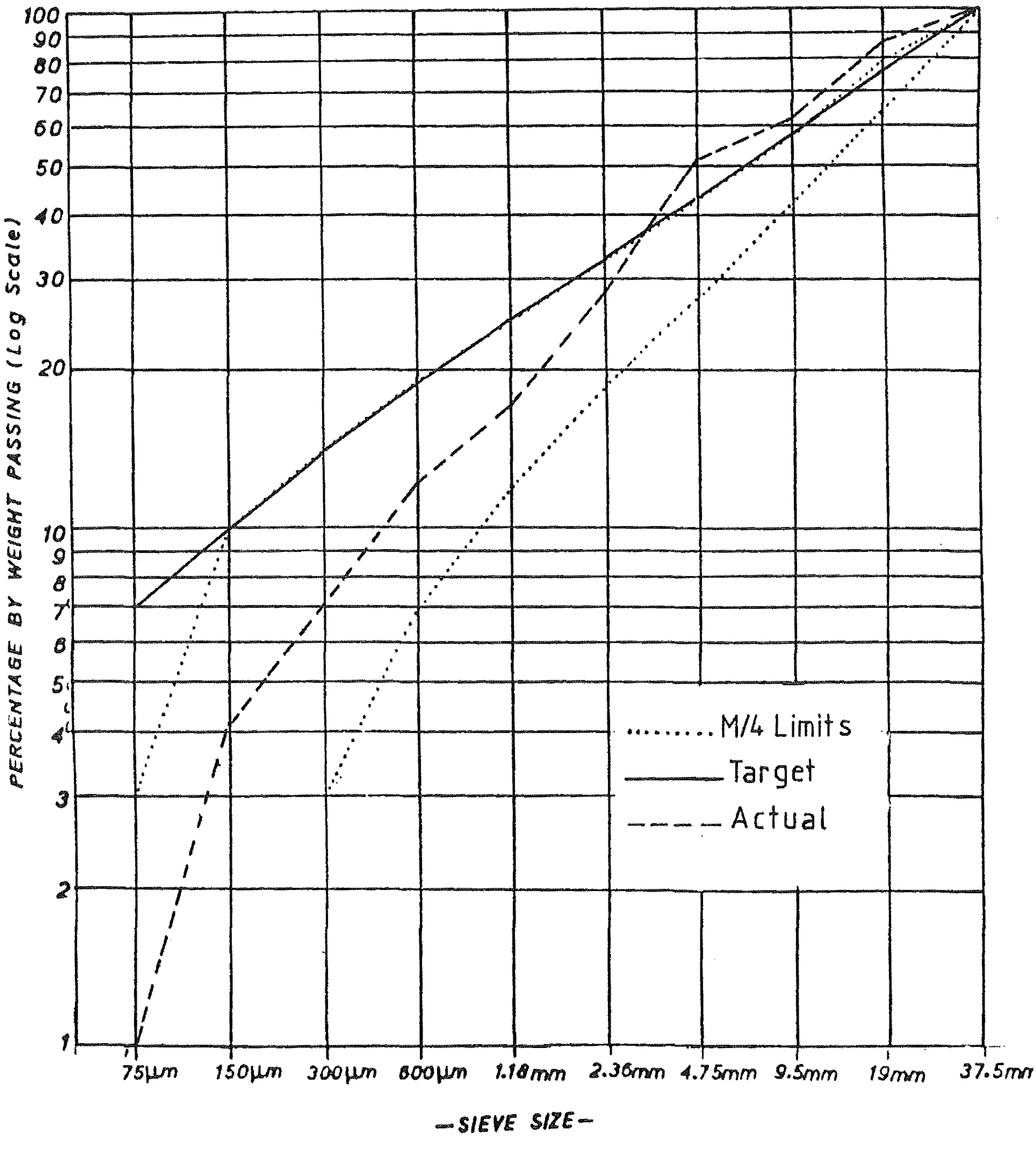


Figure B.4

UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.

# Segment: E

SIEVE ANALYSIS

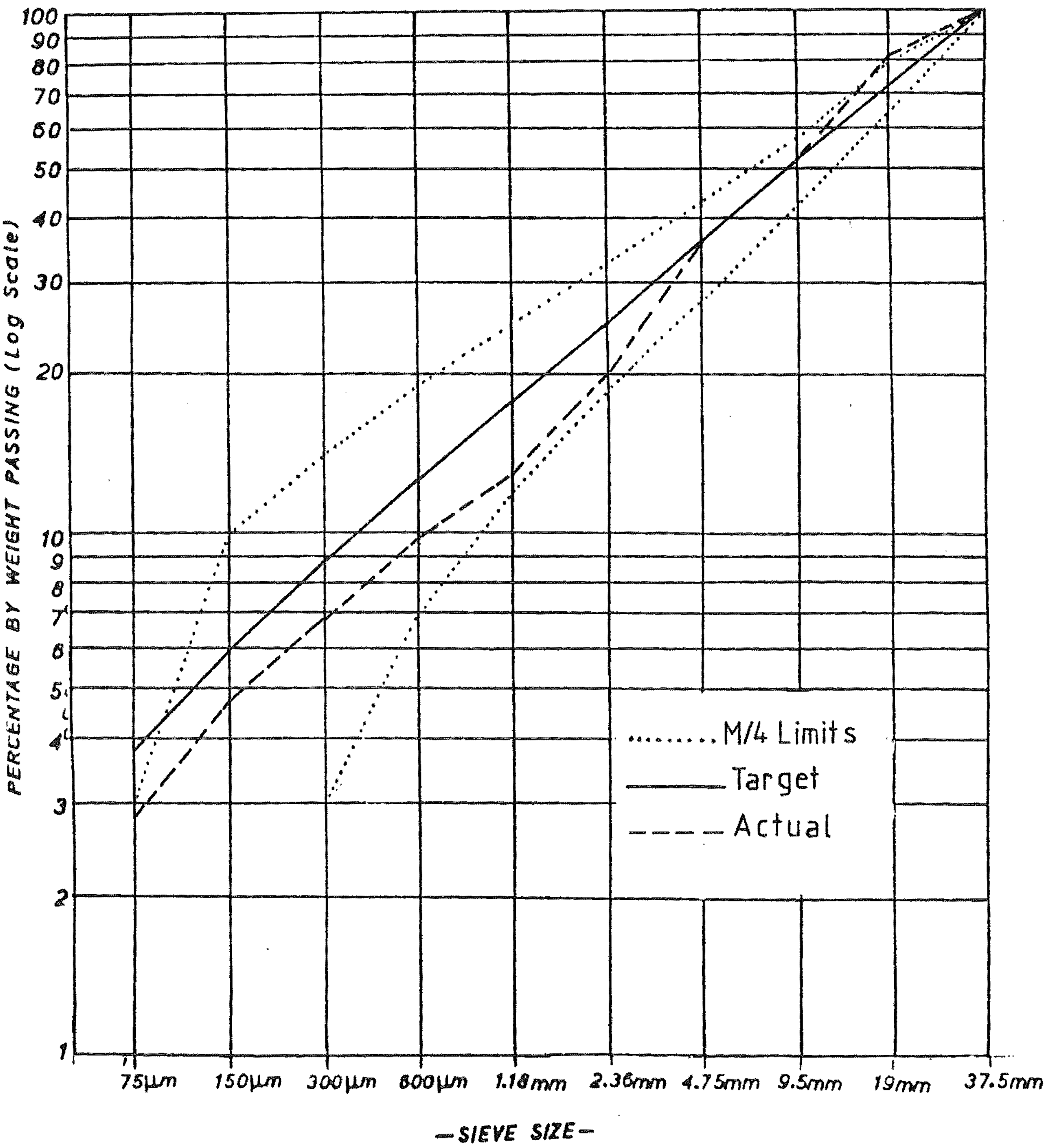


Figure B.5

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Department of Civil Engineering.

Segment: F

SIEVE ANALYSIS

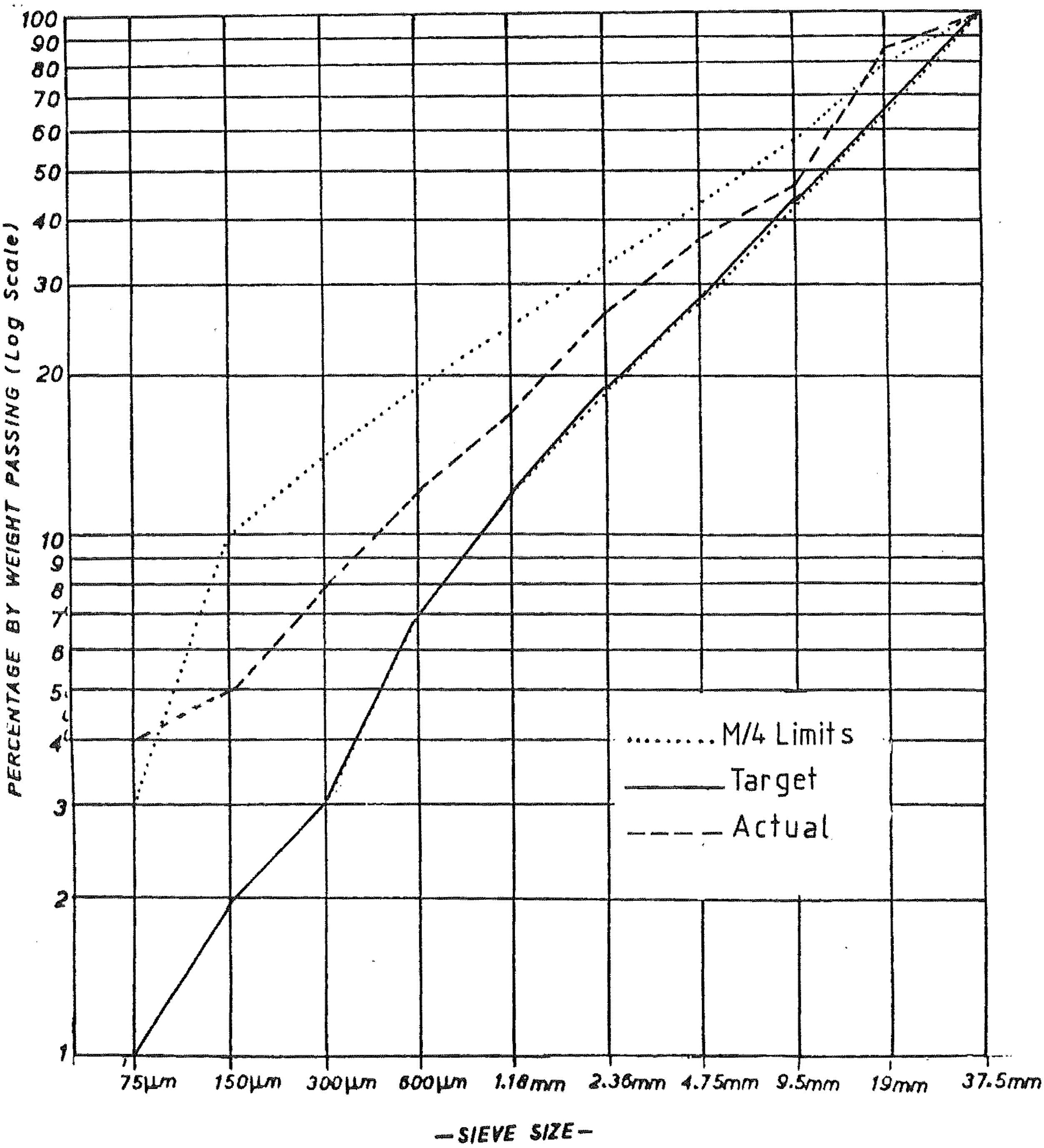


Figure B.6

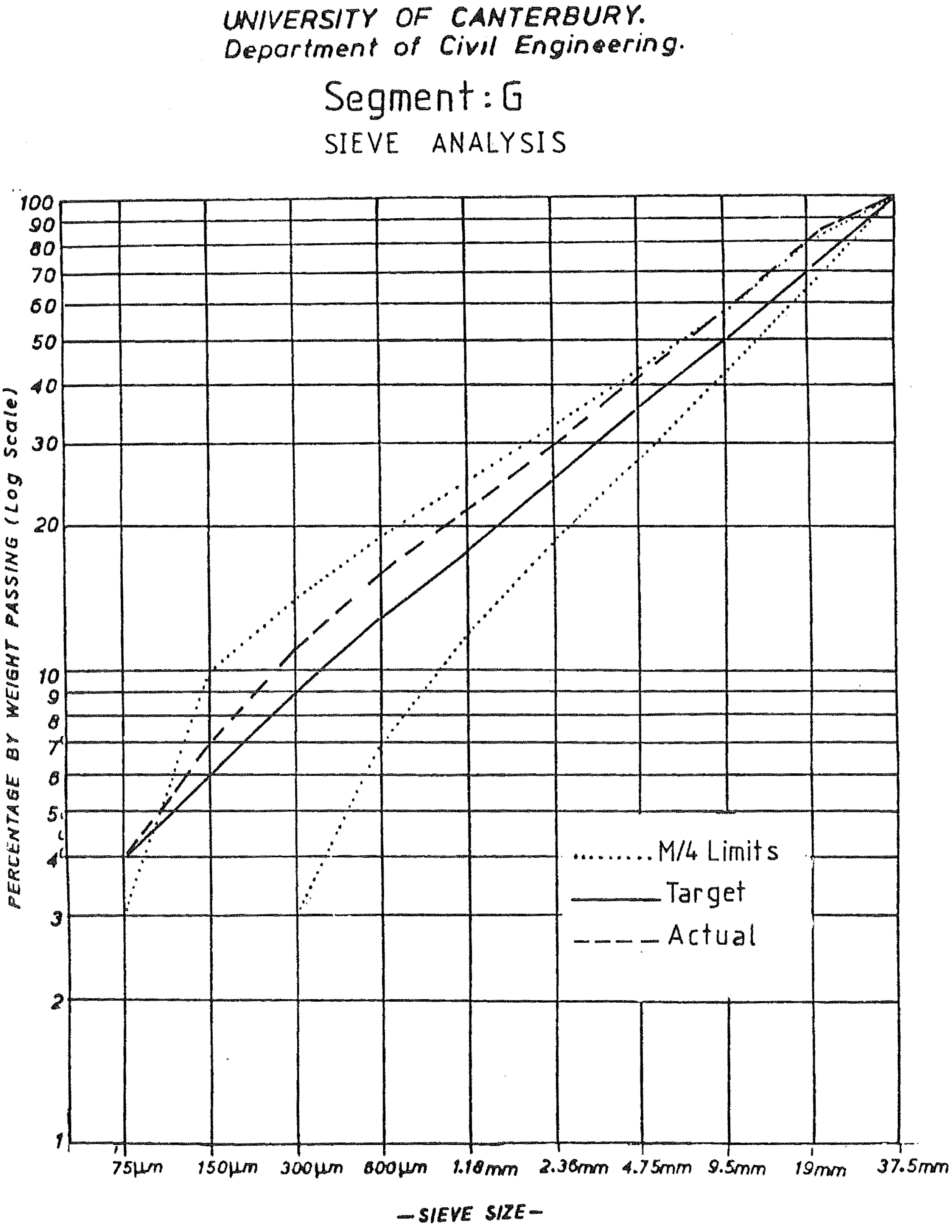
UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.
Segment: G
SIEVE ANALYSIS
PERCENTAGE BY WEIGHT PASSING (Log Scale)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
75µm
150µm
300µm
600µm
1.18mm
2.36mm
4.75mm
9.5mm
19mm
37.5mm
—SIEVE SIZE—
........M/4 Limits
Target
Actual

Figure B.7

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Department of Civil Engineering.

Segment: H

SIEVE ANALYSIS

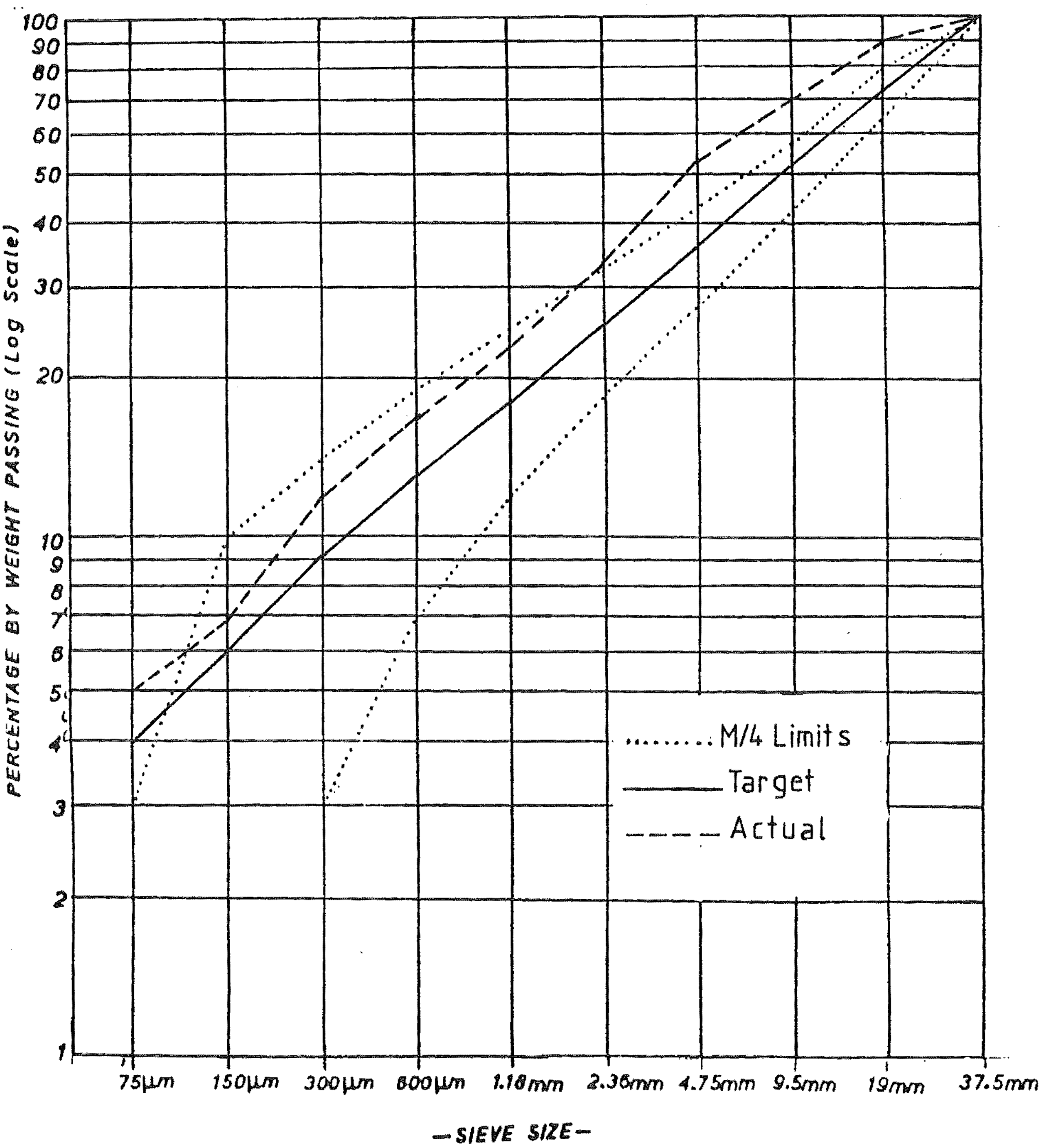


Figure B.8

*UNIVERSITY OF CANTERBURY.*
*Department of Civil Engineering.*

Segment : I

SIEVE ANALYSIS

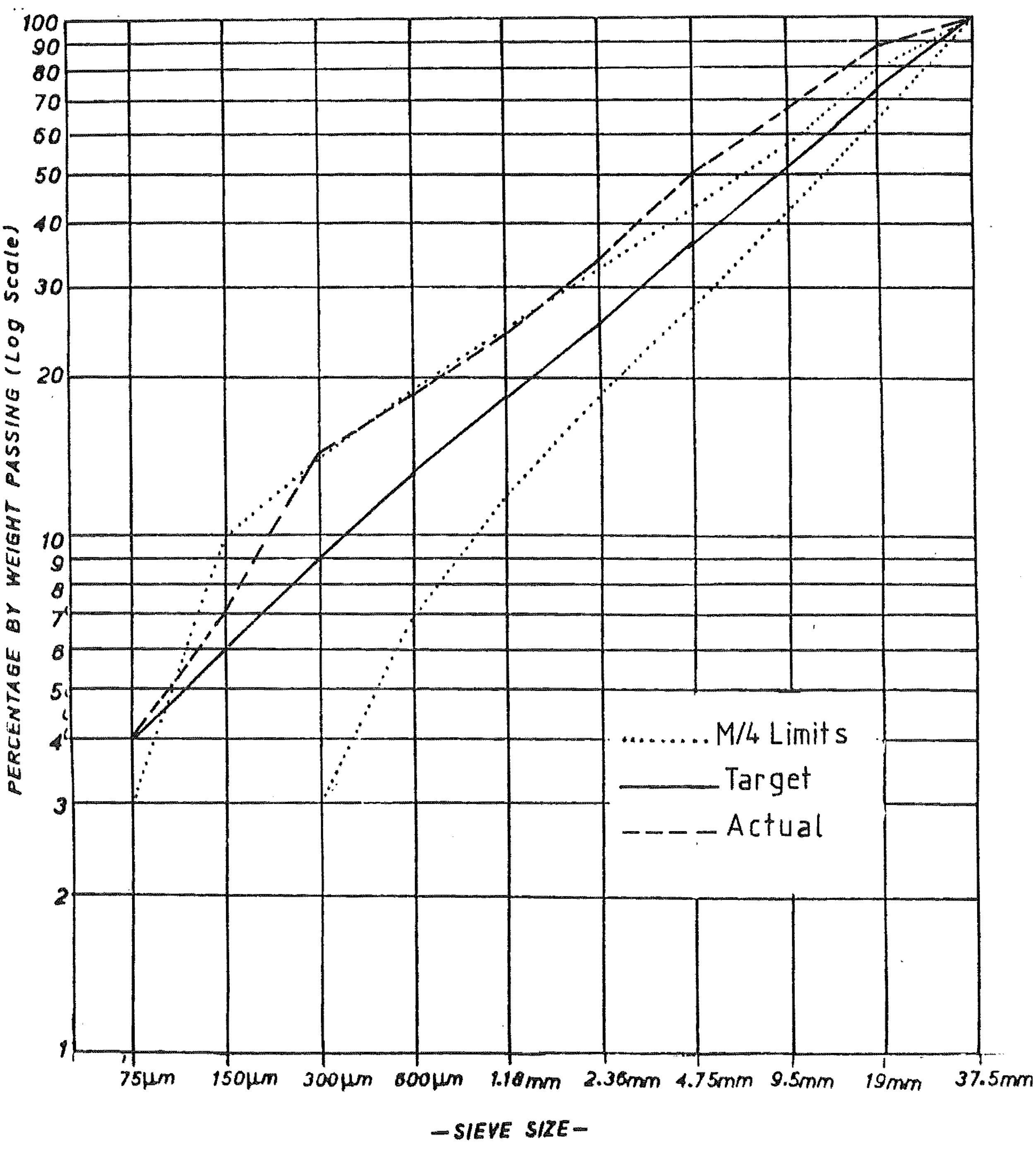


Figure B.9

UNIVERSITY OF CANTERBURY.
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Segment : A-1

SIEVE ANALYSIS

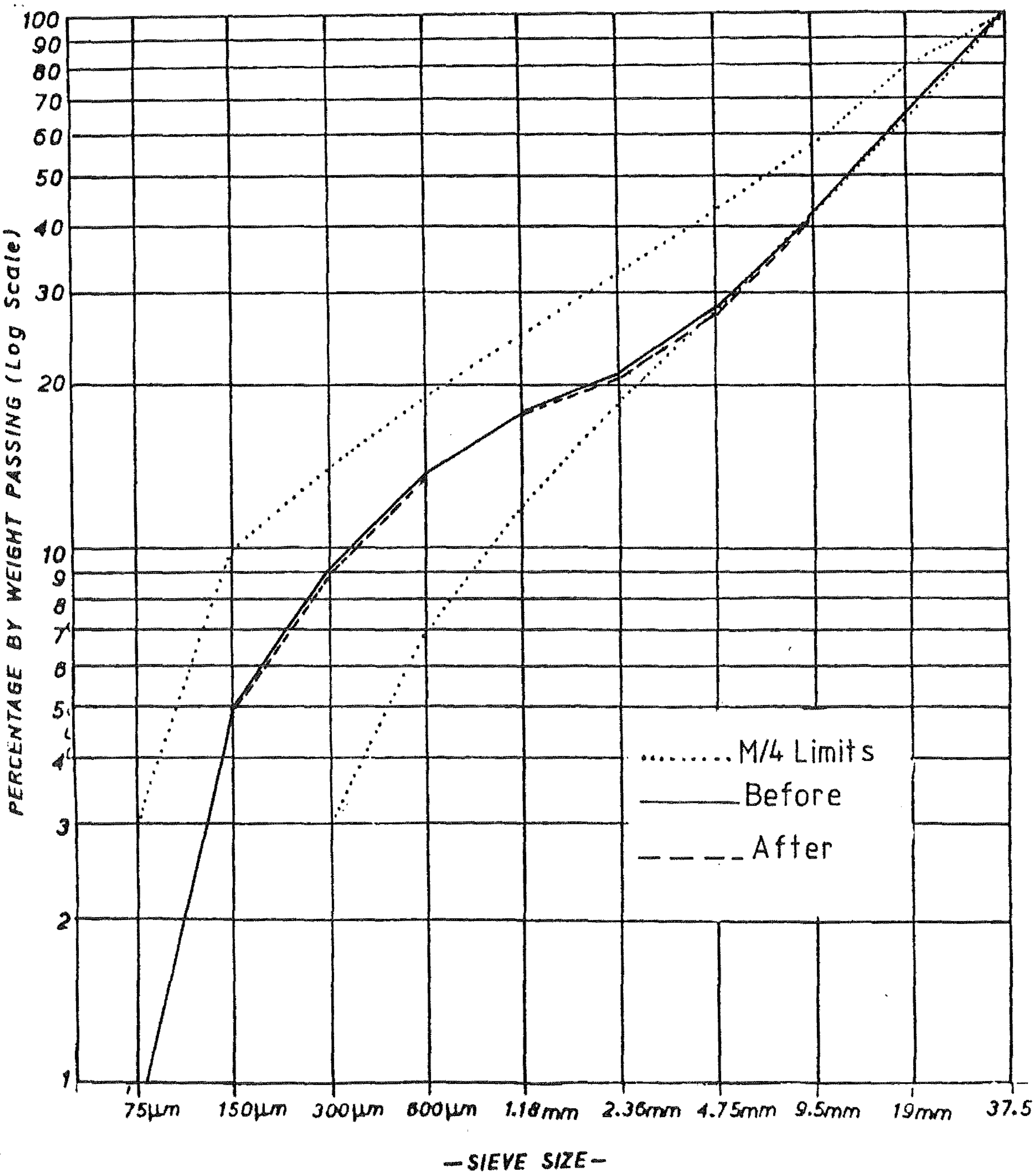


Figure B.10

UNIVERSITY OF CANTERBURY.
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Segment: D

SIEVE ANALYSIS

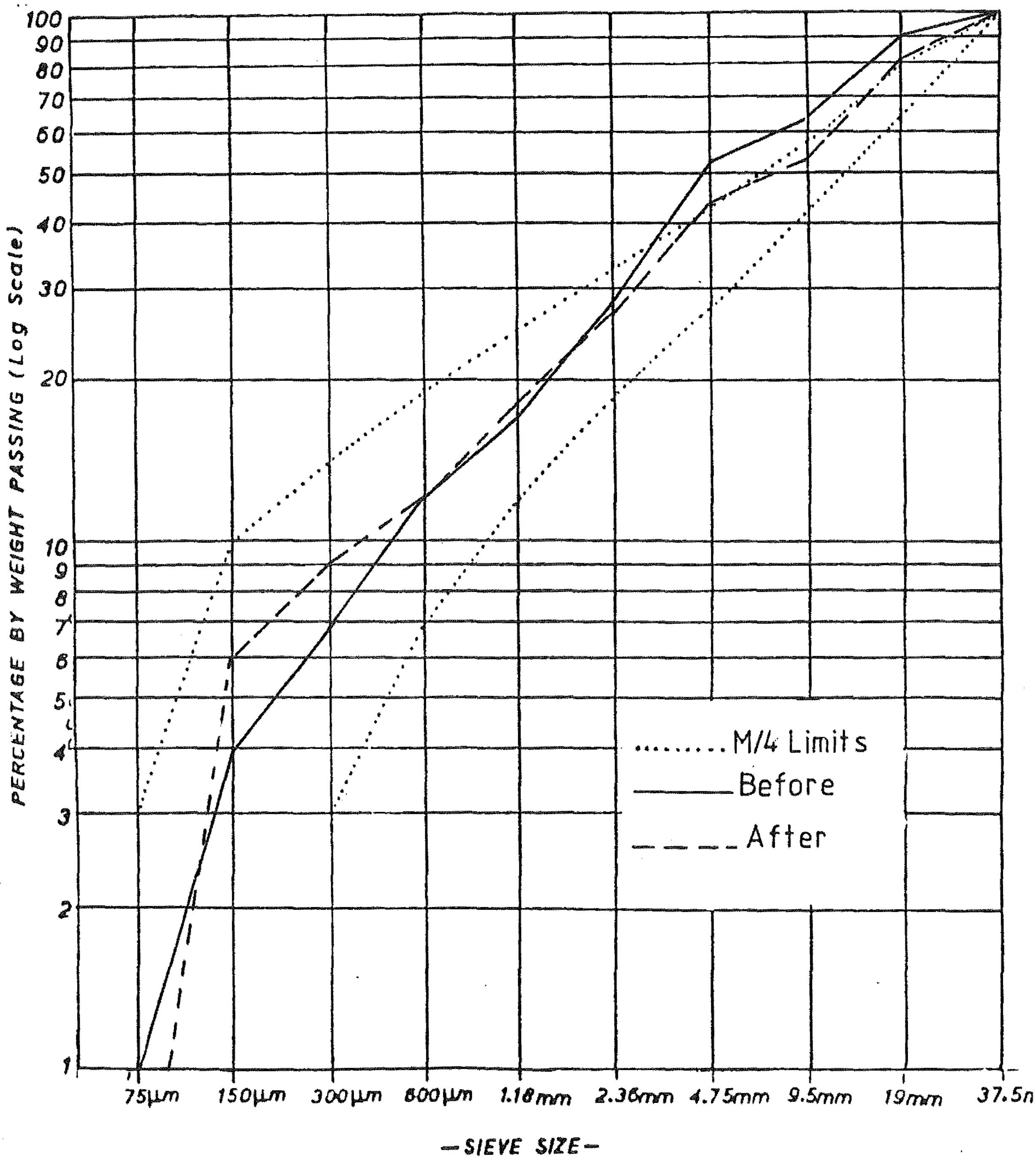


Figure B.11

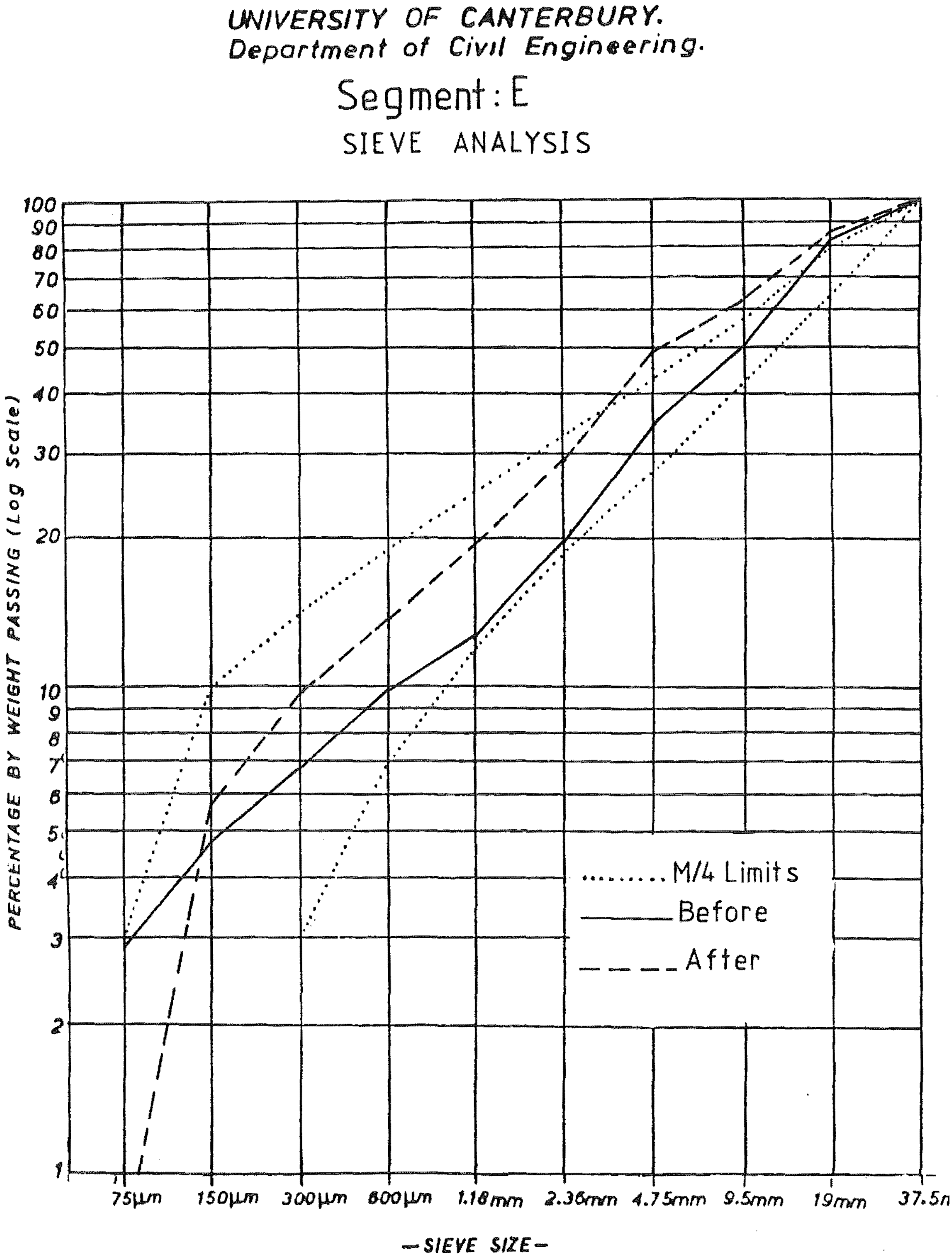
UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.
Segment: E
SIEVE ANALYSIS
PERCENTAGE BY WEIGHT PASSING (Log Scale)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
75μm
150μm
300μm
600μm
1.18mm
2.36mm
4.75mm
9.5mm
19mm
37.5mm
—SIEVE SIZE—
........M/4 Limits
———Before
— — — After

Figure B.12

UNIVERSITY OF CANTERBURY.
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Segment: F

SIEVE ANALYSIS

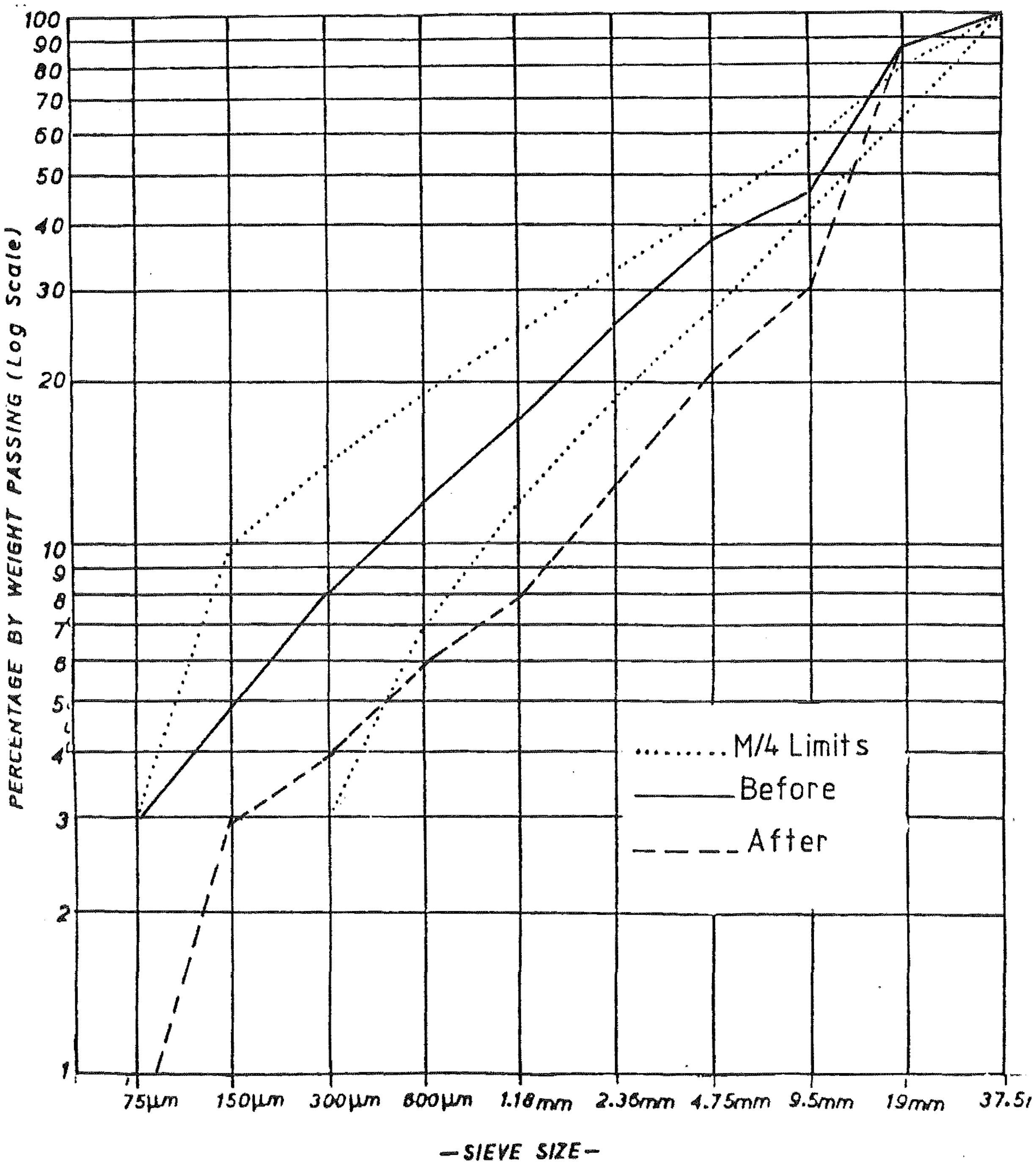



Figure B.13

UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.

# Segment: G

SIEVE ANALYSIS

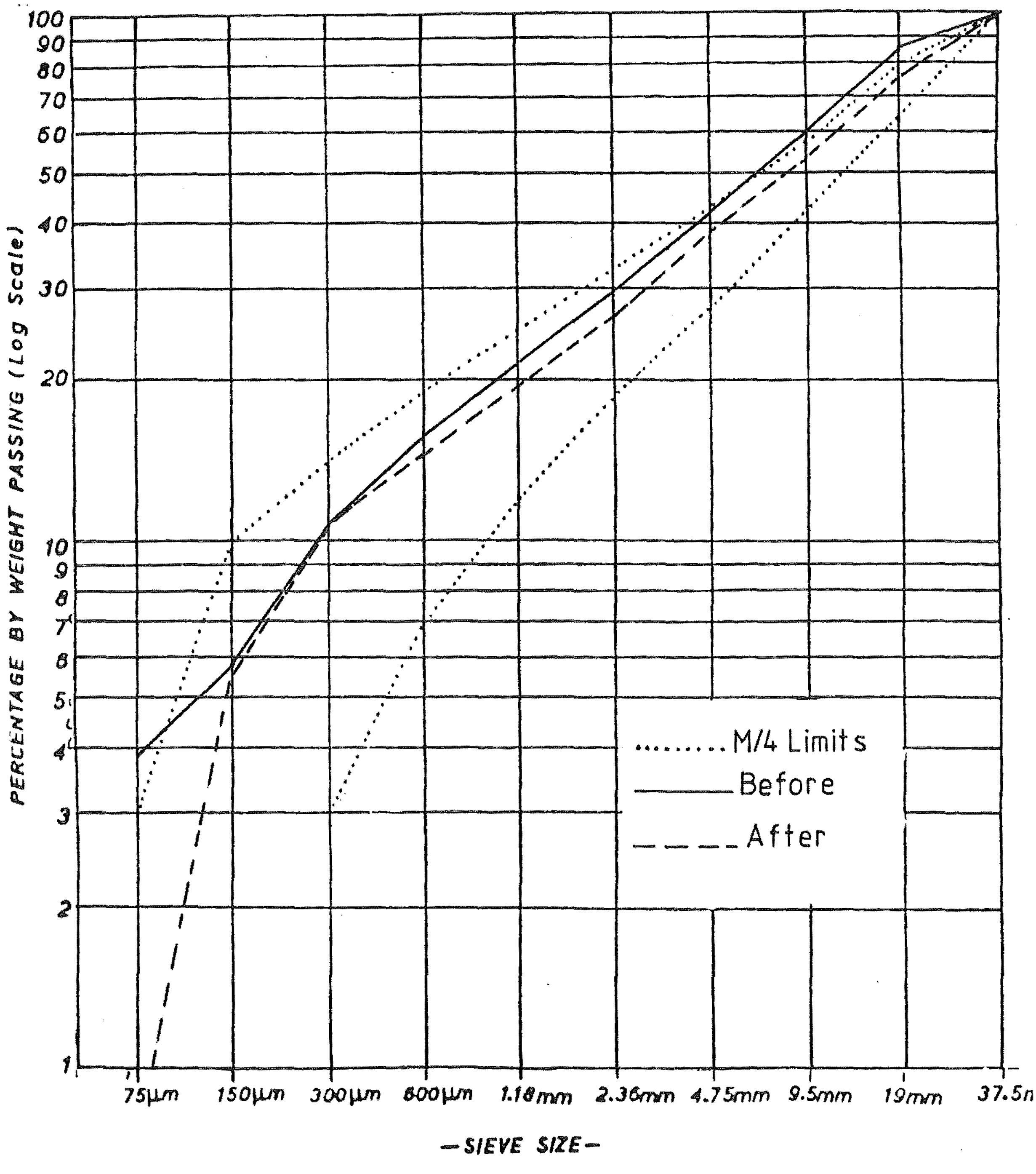



Figure B.14

UNIVERSITY OF CANTERBURY.
Department of Civil Engineering.

Segment: H

SIEVE ANALYSIS

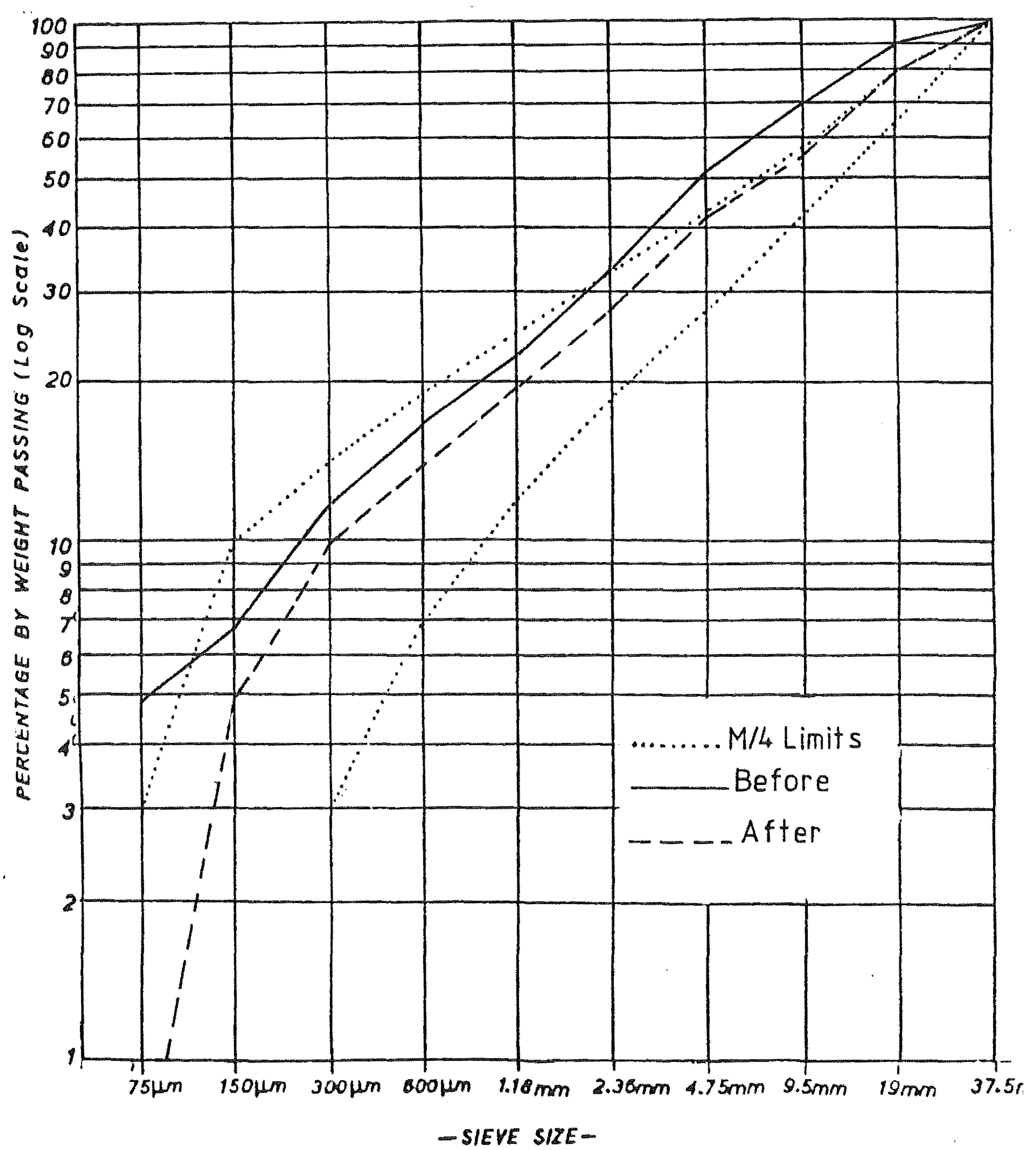



Figure B.15

# APPENDIX C

## DENSITY - COMPACTION RELATION

The behaviour of test segments against the compaction is shown in this appendix. Figure C 1, C 2 and C 3 represents Density versus number of passes of the roller for the rounded, angular and combination of rounded - angular aggregates respectively.

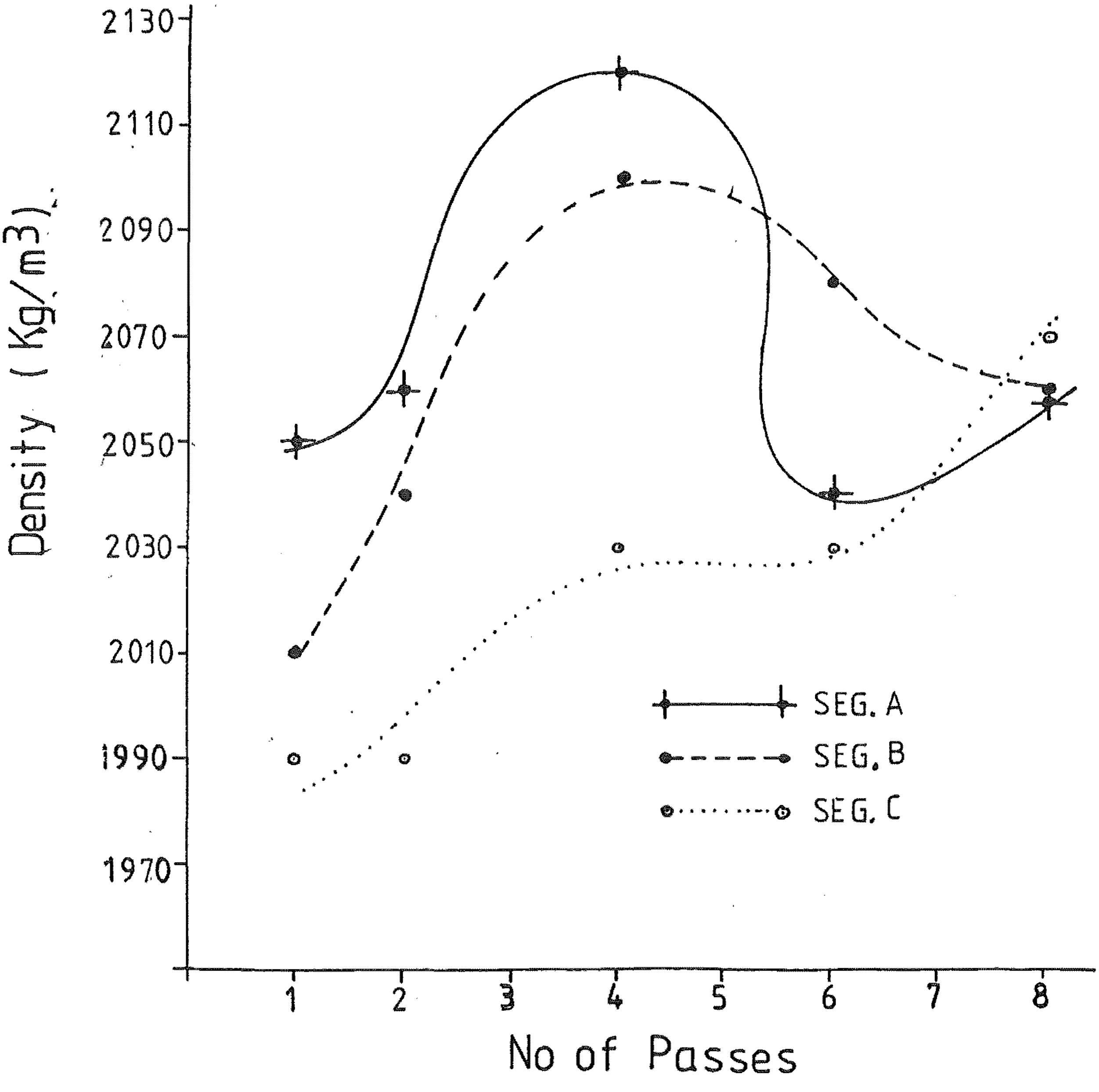

2130
2110
2090
2070
2050
2030
2010
1990
1970
Density ( Kg/m3)
SEG. A
SEG. B
SEG. C
1
2
3
4
5
6
7
8
No of Passes

Figure C.1

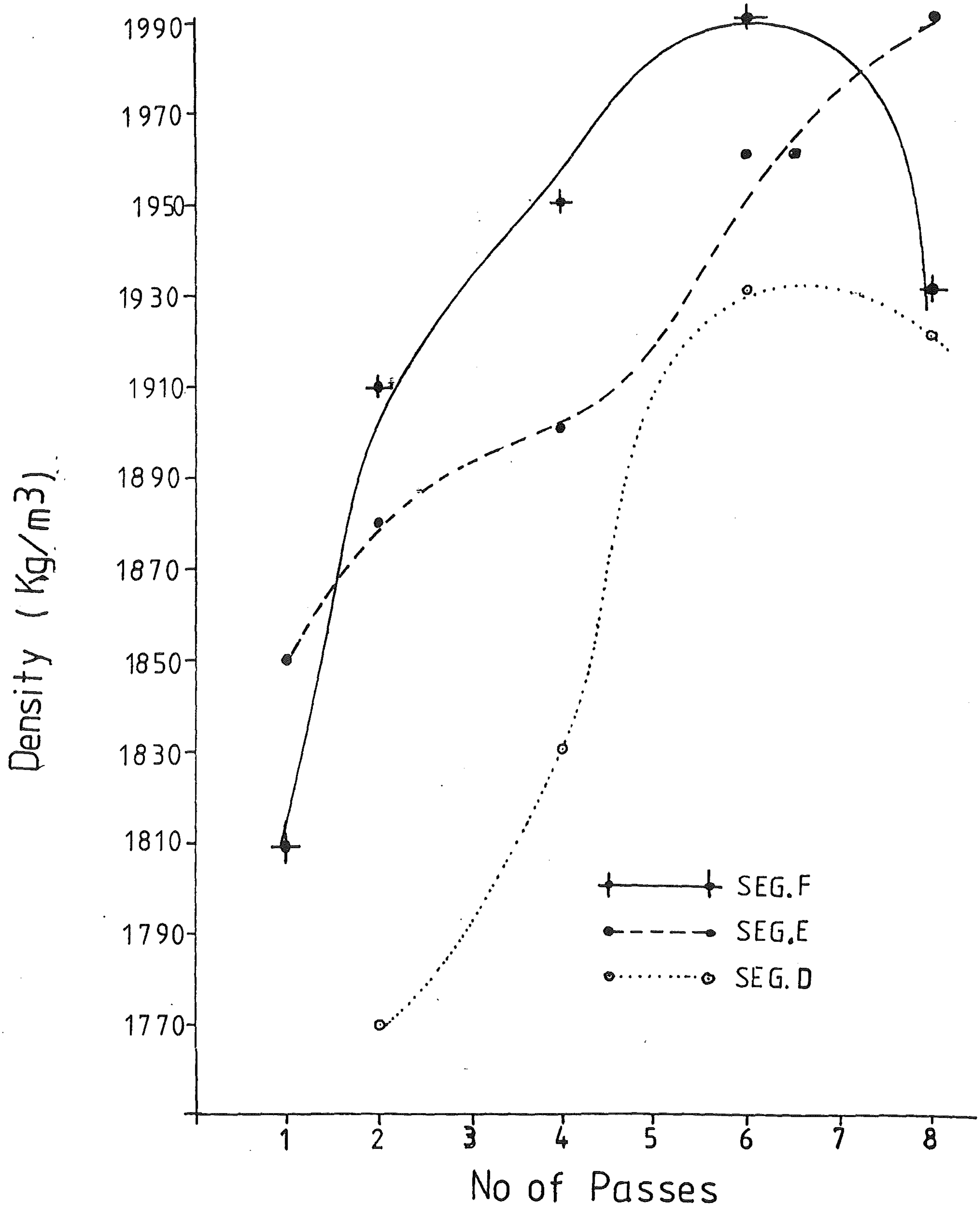
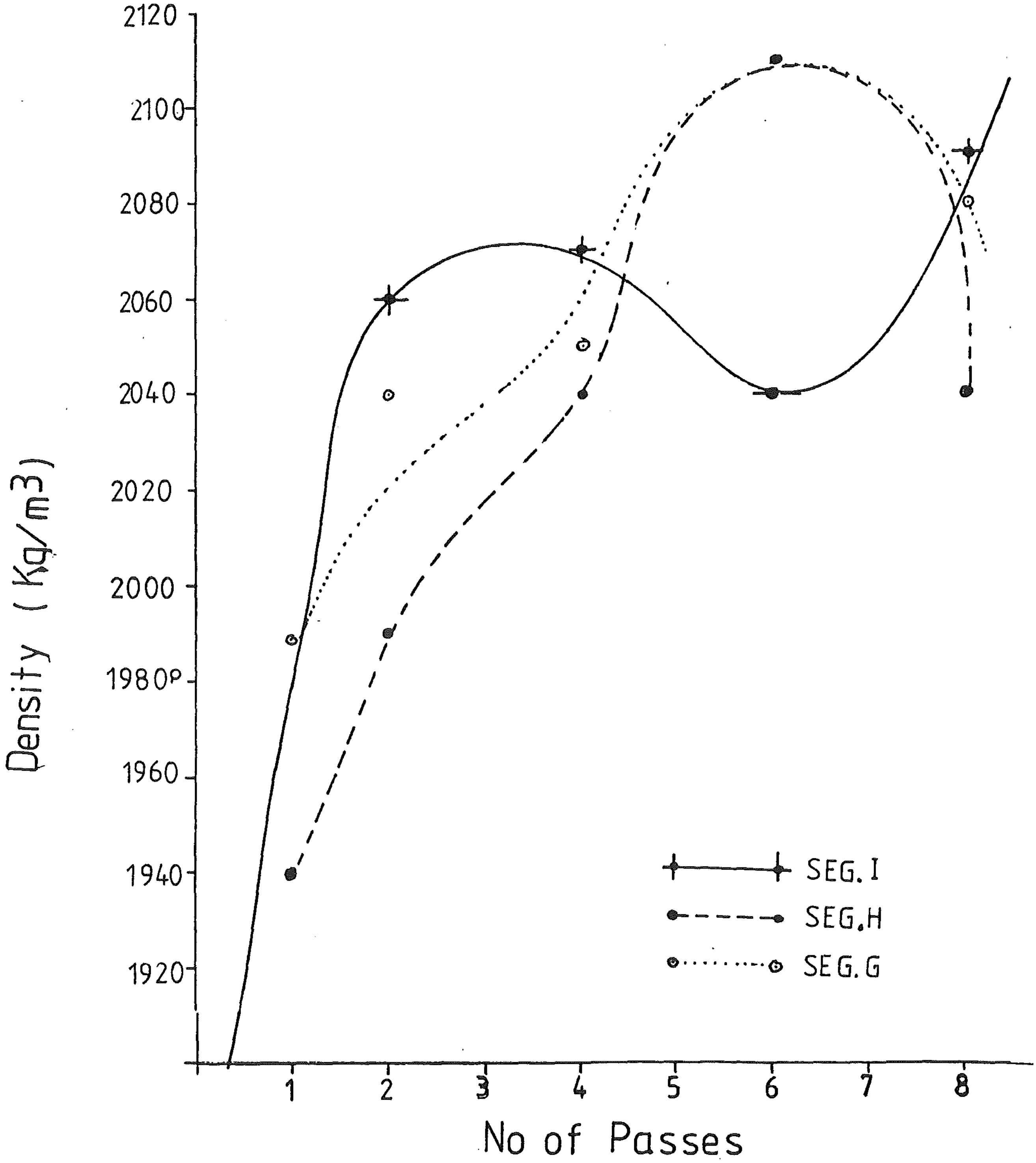

1990
1970
1950
1930
1910
1890
1870
1850
1830
1810
1790
1770
Density ( Kg/m3)
SEG.F
SEG.E
SEG.D
1
2
3
4
5
6
7
8
No of Passes

Figure C 2



2120
2100
2080
2060
2040
2020
2000
1980
1960
1940
1920
Density ( Kg/m3)
1
2
3
4
5
6
7
8
No of Passes
SEG. I
SEG. H
SEG. G


Figure C.3

# APPENDIX D

## LOAD - DEFLECTION RELATION

This appendix includes load versus deflection relation for each test segment. In each segment, observations taken at three stations are shown in Figures D 1 to D 6.

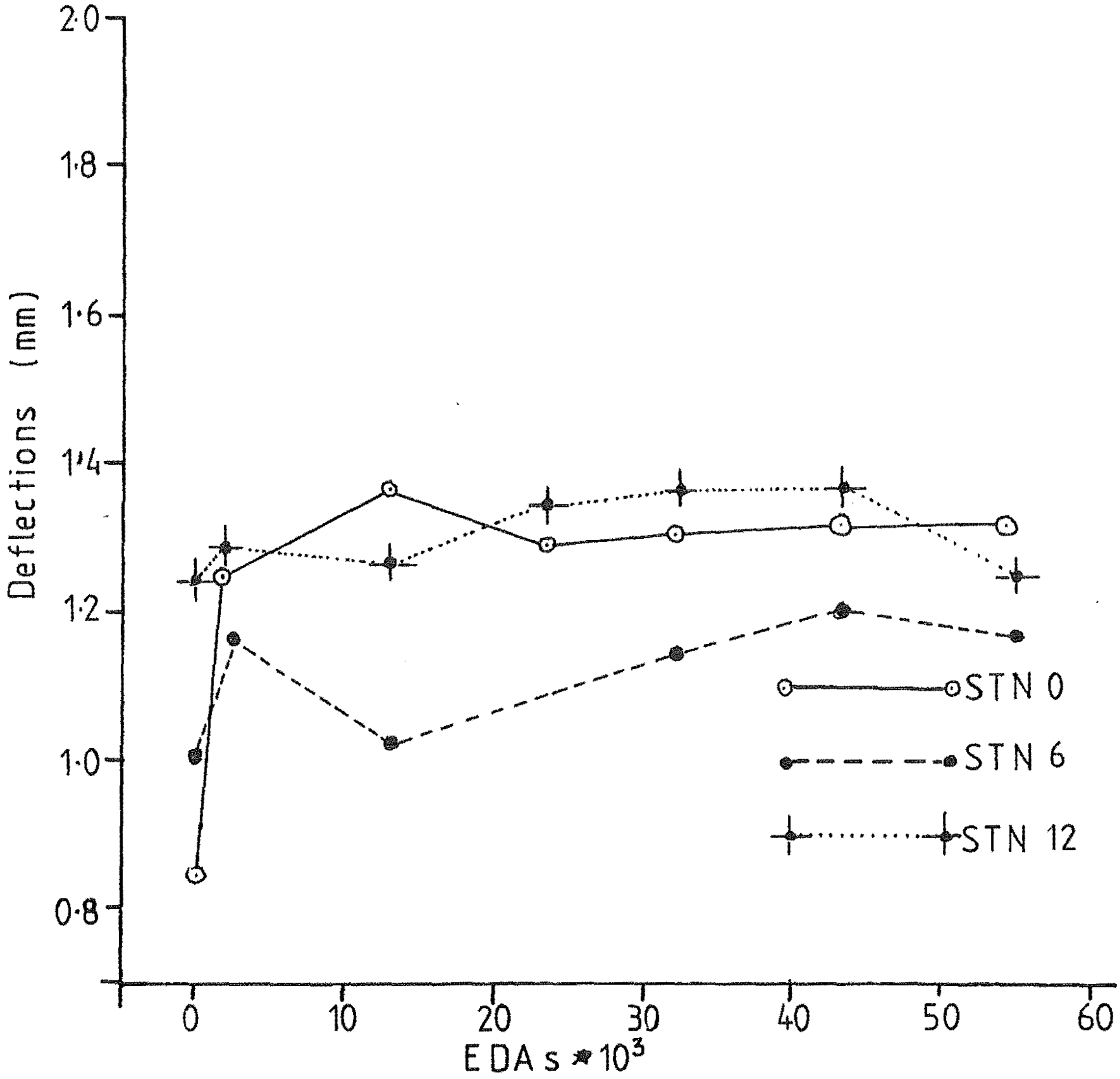

2·0
1·8
1·6
1·4
1·2
1·0
0·8
Deflections (mm)
0
10
20
30
40
50
60
EDAs * 10³
STN 0
STN 6
STN 12

Figure D.1

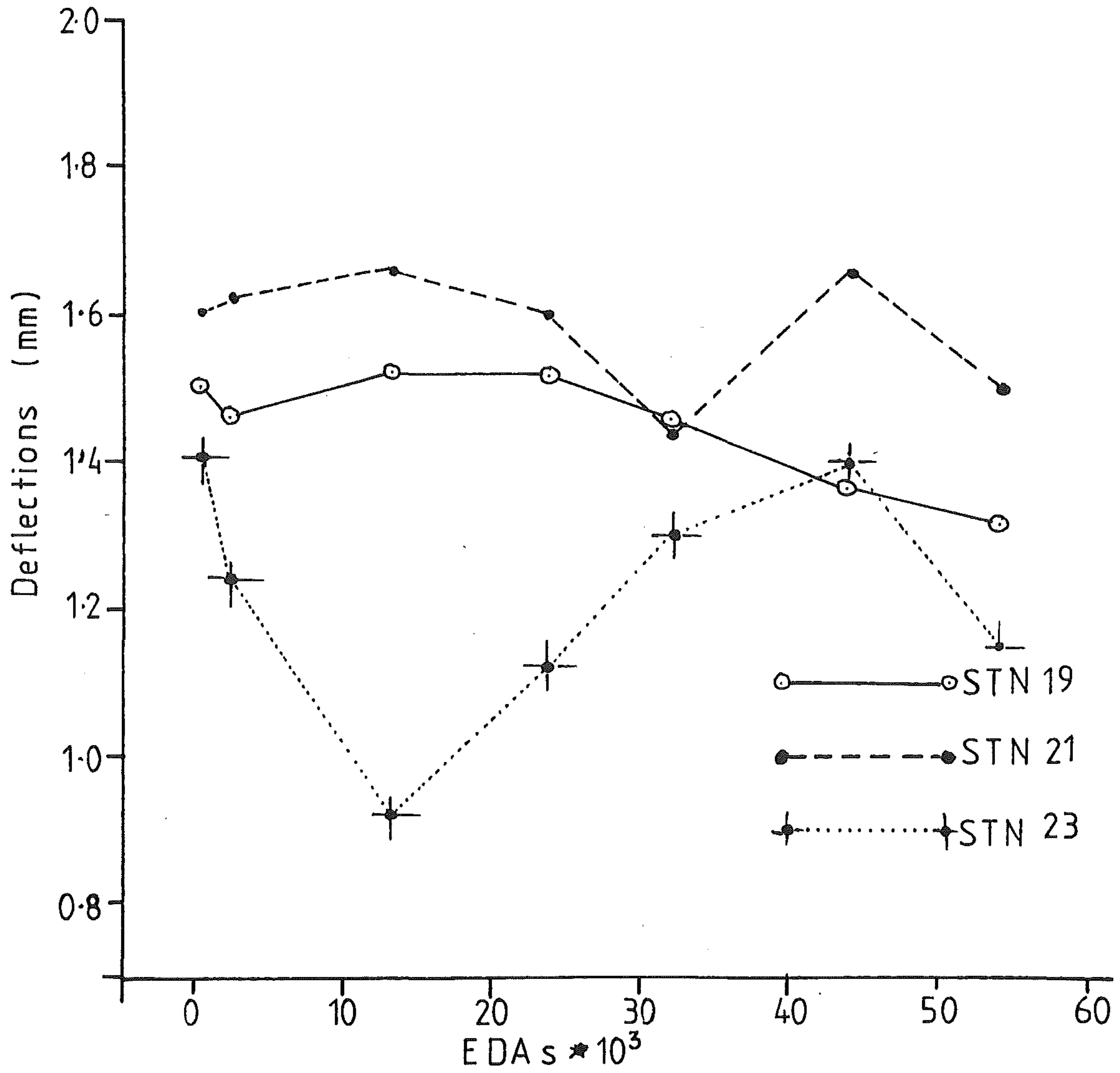

2·0
1·8
1·6
1·4
1·2
1·0
0·8
Deflections (mm)
0
10
20
30
40
50
60
EDAs * 10³
STN 19
STN 21
STN 23

Figure D.2

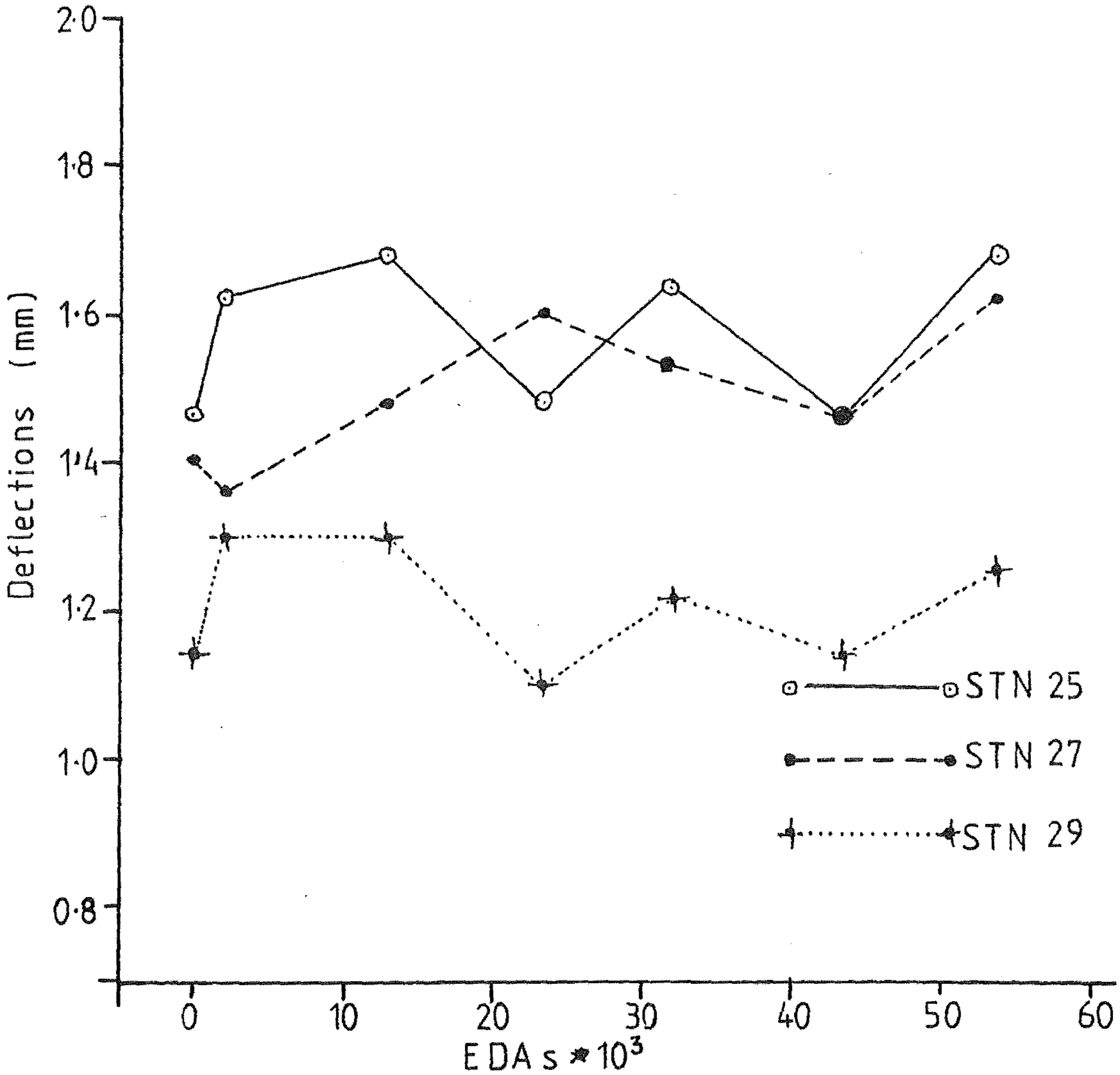
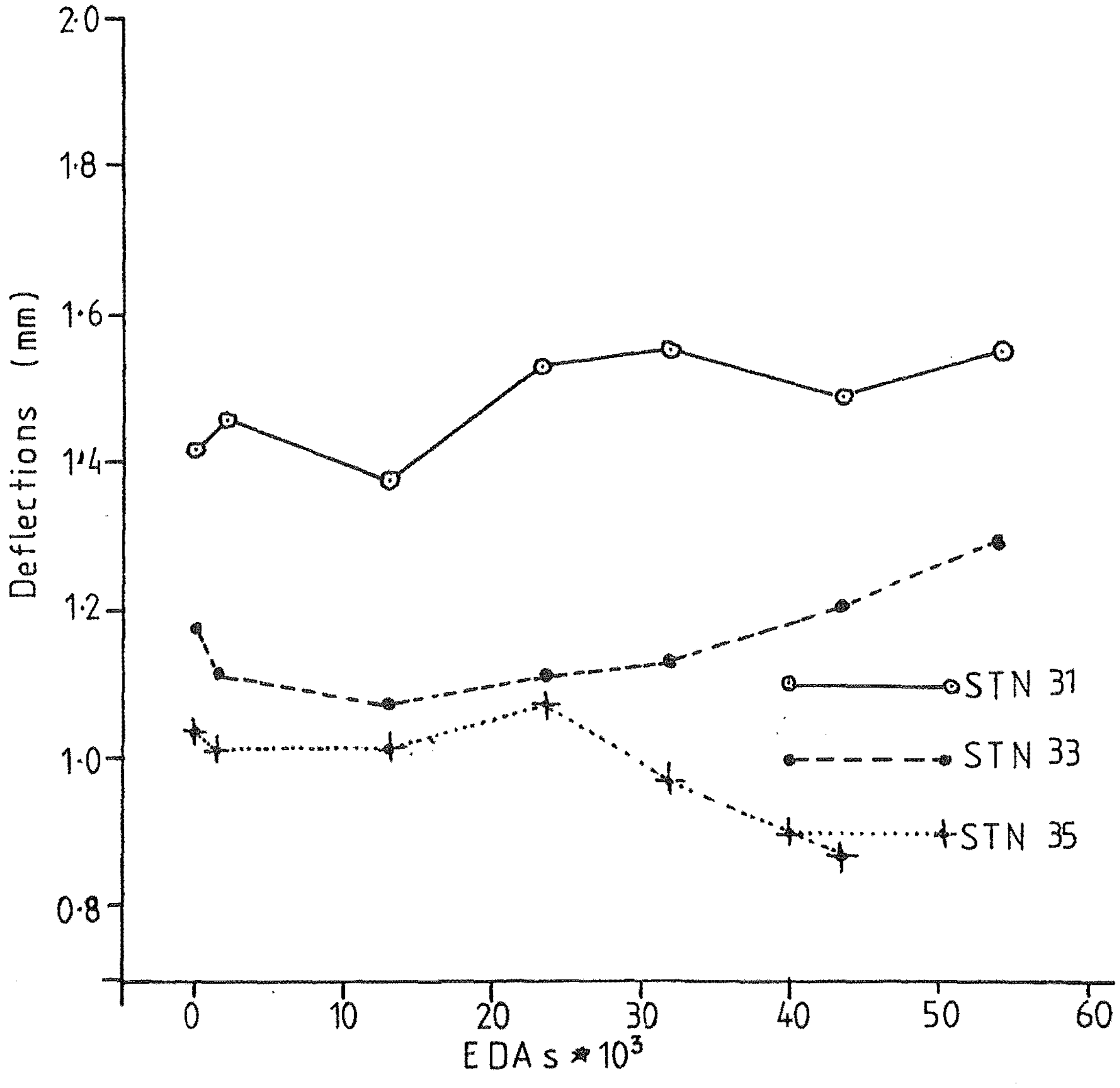
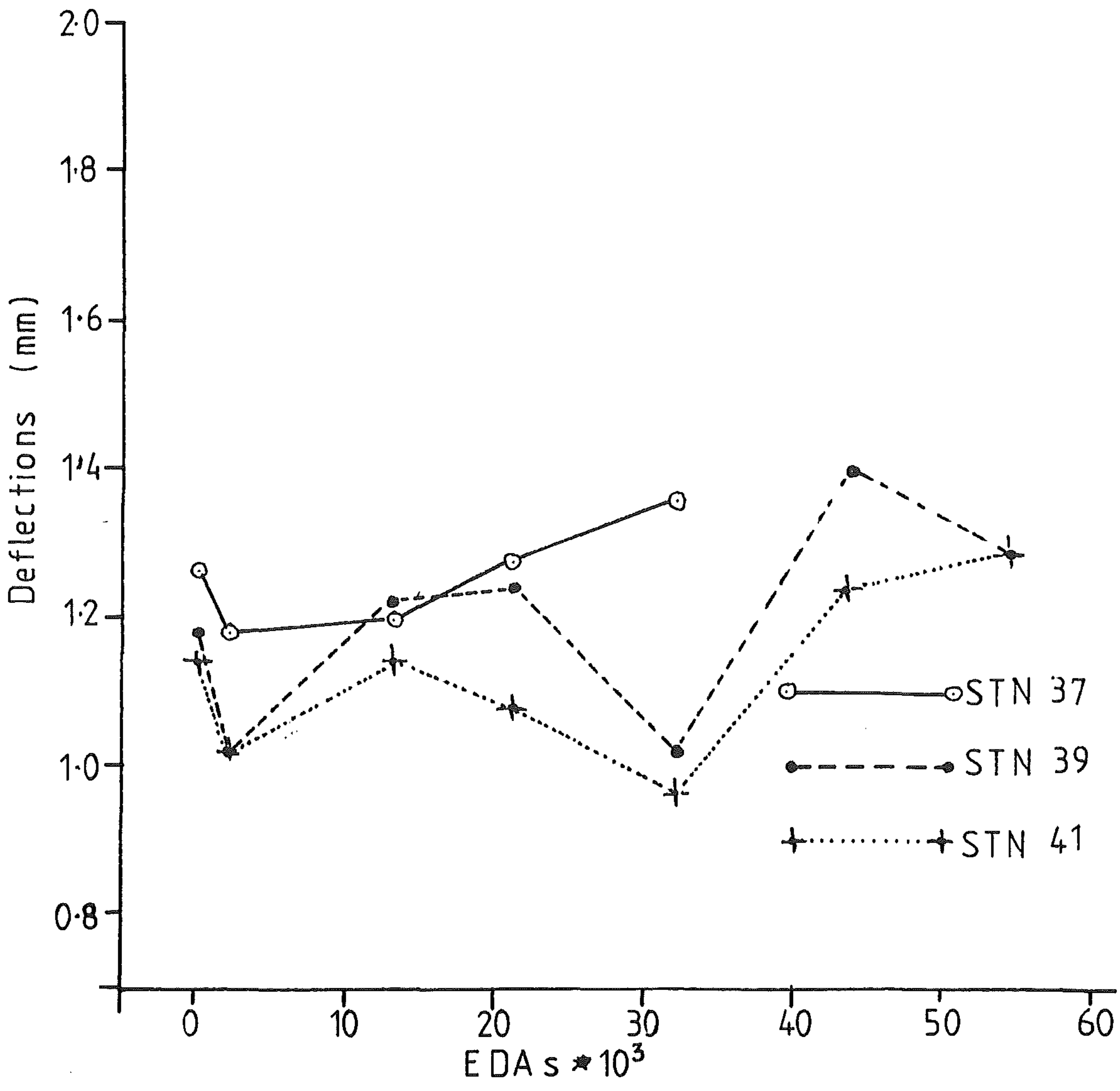

2·0
1·8
1·6
1·4
1·2
1·0
0·8
Deflections (mm)
0
10
20
30
40
50
60
EDAs * 10³
STN 25
STN 27
STN 29

Figure D.3



2·0
1·8
1·6
1·4
1·2
1·0
0·8
Deflections (mm)
0
10
20
30
40
50
60
EDAs * 10³
STN 31
STN 33
STN 35


Figure D4



2·0
1·8
1·6
1·4
1·2
1·0
0·8
Deflections (mm)
0
10
20
30
40
50
60
EDAs * $10^3$
STN 37
STN 39
STN 41


Figure D 5

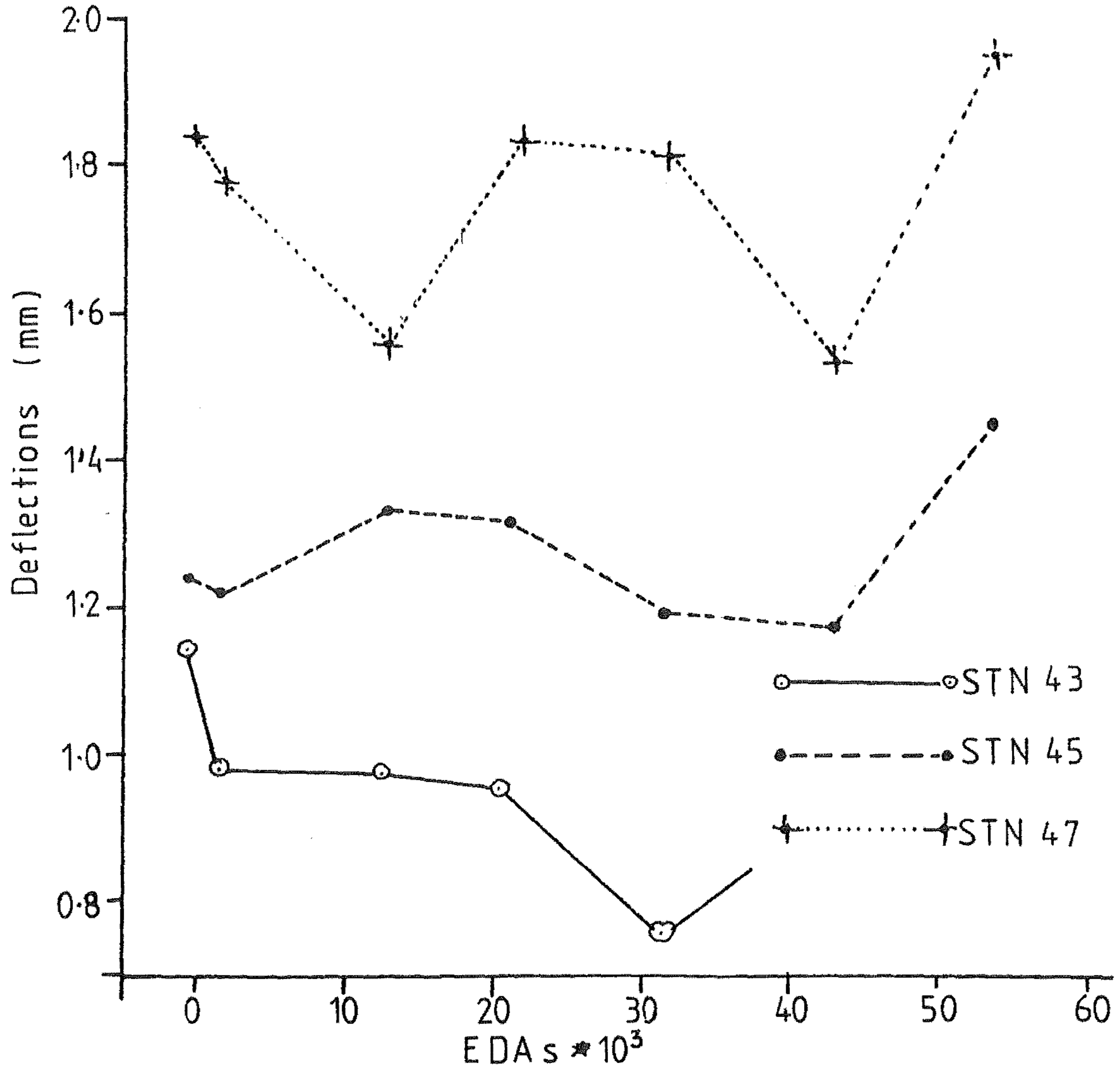

2·0
1·8
1·6
1·4
1·2
1·0
0·8
Deflections (mm)
0
10
20
30
40
50
60
EDAs * $10^3$
STN 43
STN 45
STN 47

Figure D.6

# APPENDIX E

## OBSERVATION TABLES

This appendix includes relevant data which was collected during tests, presented in the tabular form. Table E 1 and E 2 show Sieve analysis and E 3 indicates subgrade profiles. Laboratory test results of Optimum Moisture Content are tabulated in Table E 4.

TABLE E 1

SIEVE ANALYSIS OF TARGET GRADATIONS

| | 100 % Angular | | | 100 % Rounded | | | Combination | | |
|---|---|---|---|---|---|---|---|---|---|
| Segment | D | E | F | C | B | A | G | H | I |
| `n' | .4 | .5 | .6 | .4 | .5 | .6 | .5 | .5 | .5 |
| Sieve Size | | | | | | | | | |
| 37.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 19.0 | 76 | 71 | 66 | 76 | 71 | 66 | 71 | 71 | 71 |
| 9.5 | 57 | 50 | 43 | 57 | 50 | 43 | 50 | 50 | 50 |
| 4.75 | 43 | 36 | 28 | 43 | 36 | 28 | 36 | 36 | 36 |
| 2.36 | 33 | 25 | 19 | 33 | 25 | 19 | 25 | 25 | 25 |
| 1.18 | 25 | 18 | 12 | 25 | 18 | 12 | 18 | 18 | 18 |
| 0.60 | 19 | 13 | 7 | 19 | 13 | 7 | 13 | 13 | 13 |
| 0.30 | 14 | 9 | 3 | 14 | 9 | 3 | 9 | 9 | 9 |
| 0.15 | 10 | 6 | 2 | 10 | 6 | 2 | 6 | 6 | 6 |
| 0.075 | 7 | 4 | 1 | 7 | 4 | 1 | 4 | 4 | 4 |

TABLE E 2

SIEVE ANALYSIS OF ACTUAL GRADATIONS

| | 100 % Angular | | | 100 % Rounded | | | Combination | | |
|---|---|---|---|---|---|---|---|---|---|
| Segment | D | E | F | C | B | A | G | H | I |
| `n' | .4 | .5 | .6 | .4 | .5 | .6 | .5 | .5 | .5 |
| Sieve Size | | | | | | | | | |
| 37.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 19.0 | 88 | 82 | 84 | 83 | 79 | 77 | 84 | 89 | 88 |
| 9.5 | 61 | 50 | 46 | 66 | 44 | 50 | 59 | 68 | 67 |
| 4.75 | 51 | 36 | 37 | 53 | 29 | 35 | 42 | 52 | 50 |
| 2.36 | 28 | 20 | 26 | 42 | 21 | 27 | 30 | 33 | 34 |
| 1.18 | 17 | 13 | 17 | 33 | 17 | 82 | 22 | 23 | 24 |
| 0.600 | 12 | 10 | 12 | 27 | 14 | 13 | 16 | 17 | 19 |
| 0.300 | 7 | 7 | 8 | 16 | 10 | 5 | 11 | 12 | 14 |
| 0.150 | 4 | 5 | 5 | 3 | 3 | 1 | 6 | 7 | 7 |
| 0.075 | 1 | 3 | 3 | 1 | 1 | 0 | 4 | 5 | 4 |

TABLE E 3

SUBGRADE PROFILE

| Seg. | Type of Profile (mm) | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Radial offset from inner track wall | | | | | | | | | | |
| A1 | Initial | 225 | 229 | 227 | 223 | 222 | 223 | 222 | 222 | 221 | 225 | 225 |
| | Final | 248 | 260 | 235 | 240 | 238 | 235 | 234 | 235 | 234 | 234 | 240 |
| D | Initial | 230 | 225 | 225 | 224 | 223 | 226 | 224 | 223 | 226 | 225 | 221 |
| | Final | 234 | 234 | 234 | 234 | 234 | 234 | 225 | 230 | 222 | 227 | 225 |
| E | Initial | 240 | 240 | 240 | 236 | 237 | 234 | 230 | 230 | 227 | 228 | 225 |
| | Final | 250 | 248 | 245 | 245 | 250 | 243 | 240 | 235 | 235 | 235 | 240 |
| F | Initial | 221 | 222 | 219 | 217 | 215 | 216 | 217 | 214 | 215 | 225 | 228 |
| | Final | 228 | 225 | 228 | 220 | 222 | 222 | 222 | 222 | 222 | 221 | 234 |
| G | Initial | 240 | 234 | 233 | 232 | 231 | 229 | 228 | 227 | 229 | 230 | 231 |
| | Final | 240 | 243 | 240 | 240 | 240 | 235 | 234 | 234 | 234 | 234 | 239 |
| H | Initial | 235 | 235 | 230 | 229 | 225 | 218 | 221 | 221 | 218 | 218 | 218 |
| | Final | 240 | 240 | 235 | 240 | 238 | 234 | 234 | 225 | 225 | 223 | 224 |

TABLE E 4

OPTIMUM MOISTURE CONTENT

| Material | Grad. Expn. `n' | Segment | Maximum Dry Density $Kg/m^3$ | Opt. Moisture Content % |
|---|---|---|---|---|
| 100 % Ang. | 0.4 | D | 1970 | 2.6 |
| 100 % Ang. | 0.5 | E | 1946 | 3.6 |
| 100 % Ang. | 0.6 | F | 1988 | 6.3 |
| 50%R+50%A. | 0.5 | G | * | * |
| 70%R+30%A | 0.5 | H | 2073 | 7.8 |

* Due to high void content in the material, a result was unable to be obtained.

Plate 1: Compacted Subgrade

Plate 2: Geomembrane

Placing of Basecourse
Plate 3


Shoving in Segment I
Plate 4


Trafic Simulation
Plate 5


Profilometer
Plate 6


Localised Segregation
Plate 7


Bulging in Segment
Plate 8

Classn:

INFLUENCE OF PARTICLE SHAPE AND VOID RATIO ON BASE STABILITY

V.K.Joshi

Abstract: The rounded and angular aggregates with different gradations were tested in full scale road structure. Performance was evaluated by comparing compactive effort, deflections and vertical deformations. Cohesiveness of fines and blending were found to be important factors while shape factor was governing the performance.

Department of Civil Engineering, University of Canterbury Master of Engineering Report, 1989.